US008900963B2

(12) **United States Patent**
Sills et al.

(10) **Patent No.: US 8,900,963 B2**

(45) **Date of Patent: Dec. 2, 2014**

(54) **METHODS OF FORMING SEMICONDUCTOR DEVICE STRUCTURES, AND RELATED STRUCTURES**

(75) Inventors: **Scott E. Sills**, Boise, ID (US); **Dan B. Millward**, Boise, ID (US)

(73) Assignee: **Micron Technology, Inc.**, Boise, ID (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 314 days.

(21) Appl. No.: **13/287,814**

(22) Filed: **Nov. 2, 2011**

(65) **Prior Publication Data**

US 2013/0105755 A1 May 2, 2013

(51) **Int. Cl.**
H01L 21/20 (2006.01)
H01L 45/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 45/1233*** (2013.01); ***H01L 45/145*** (2013.01); ***H01L 45/085*** (2013.01); ***H01L 45/1683*** (2013.01); ***H01L 45/141*** (2013.01); ***H01L 45/1658*** (2013.01); ***H01L 45/146*** (2013.01)
USPC **438/381**; 438/23; 257/2; 257/E21.52

(58) **Field of Classification Search**
CPC C08F 10/00; C08F 8/42; C08L 2666/02; C08L 53/00; H01L 21/02118; H01L 21/31058; H01L 51/0002; H01L 51/0034; H01L 51/0043; H01L 45/1658; H01L 45/085
USPC 438/23, 50, 381; 257/2, E45.002, 257/E21.52
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,623,674	A	11/1986	Bailey
4,797,357	A	1/1989	Mura et al.
4,818,713	A	4/1989	Feygenson
4,877,647	A	10/1989	Klabunde
5,328,810	A	7/1994	Lowrey et al.
5,374,367	A	12/1994	Edamura et al.
5,382,373	A	1/1995	Carlson
5,482,656	A	1/1996	Hiraoka et al.
5,512,131	A	4/1996	Kumar et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1562730	A	1/2005
CN	1799131	A	7/2006

(Continued)

OTHER PUBLICATIONS

Huang et al., "Stretchable gold conductors on elastomeric substrates," Applied Physics Letters, vol. 82, No. 15, Apr. 14, 2003, pp. 2404-2406.

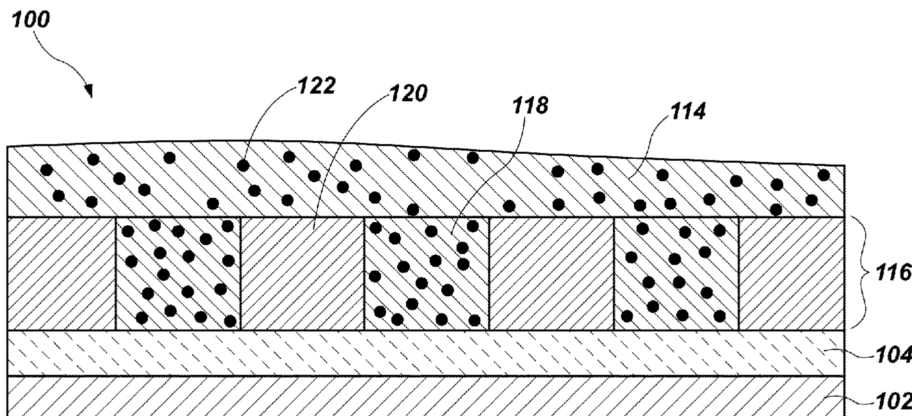
(Continued)

Primary Examiner — Colleen A Matthews
Assistant Examiner — Colleen E Snow
(74) *Attorney, Agent, or Firm* — TraskBritt

(57) **ABSTRACT**

A method of forming a semiconductor device structure. The method comprises forming a block copolymer assembly comprising at least two different domains over an electrode. At least one metal precursor is selectively coupled to the block copolymer assembly to form a metal-complexed block copolymer assembly comprising at least one metal-complexed domain and at least one non-metal-complexed domain. The metal-complexed block copolymer assembly is annealed in to form at least one metal structure. Other methods of forming a semiconductor device structures are described. Semiconductor device structures are also described.

30 Claims, 18 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,538,655 A 7/1996 Fauteux et al.
5,580,700 A 12/1996 Rahman
5,620,850 A 4/1997 Bamdad et al.
5,622,668 A 4/1997 Thomas et al.
5,772,905 A 6/1998 Chou
5,834,583 A 11/1998 Hancock et al.
5,849,810 A 12/1998 Muller et al.
5,879,582 A 3/1999 Havelka et al.
5,879,853 A 3/1999 Azuma
5,891,356 A 4/1999 Inoue et al.
5,904,824 A 5/1999 Oh et al.
5,925,259 A 7/1999 Biebuyck et al.
5,948,470 A 9/1999 Harrison et al.
5,958,704 A 9/1999 Starzl et al.
6,051,869 A 4/2000 Pan et al.
6,111,323 A 8/2000 Carter et al.
6,143,647 A 11/2000 Pan et al.
6,153,495 A 11/2000 Kub et al.
6,207,787 B1 3/2001 Fahey et al.
6,251,791 B1 6/2001 Tsai et al.
6,270,946 B1 8/2001 Miller
6,309,580 B1 10/2001 Chou
6,310,138 B1 10/2001 Yonezawa et al.
6,312,971 B1 11/2001 Amundson et al.
6,368,871 B1 4/2002 Christel et al.
6,403,382 B1 6/2002 Zhu et al.
6,414,164 B1 7/2002 Afzali-Ardakani et al.
6,423,465 B1 7/2002 Hawker et al.
6,423,474 B1 7/2002 Holscher
6,503,841 B1 1/2003 Criscuolo et al.
6,506,660 B2 1/2003 Holmes et al.
6,517,933 B1 2/2003 Soane et al.
6,518,194 B2 2/2003 Winningham et al.
6,537,920 B1 3/2003 Krivokapic
6,548,830 B1 4/2003 Noguchi et al.
6,565,763 B1 5/2003 Asakawa et al.
6,565,764 B2 5/2003 Hiraoka et al.
6,566,248 B1 5/2003 Wang et al.
6,569,528 B2 5/2003 Nam et al.
6,573,030 B1 6/2003 Fairbairn et al.
6,592,764 B1 7/2003 Stucky et al.
6,630,520 B1 10/2003 Bruza et al.
6,635,912 B2 10/2003 Ohkubo
6,656,308 B2 12/2003 Hougham et al.
6,679,996 B1 1/2004 Yao
6,682,660 B2 1/2004 Sucholeiki et al.
6,689,473 B2 2/2004 Guire et al.
6,699,797 B1 3/2004 Morris et al.
6,713,238 B1 3/2004 Chou et al.
6,746,825 B2 6/2004 Nealey et al.
6,767,693 B1 7/2004 Okoroanyanwu
6,780,492 B2 8/2004 Hawker et al.
6,781,166 B2 8/2004 Lieber et al.
6,797,202 B2 9/2004 Endo et al.
6,809,210 B2 10/2004 Chandross
6,812,132 B2 11/2004 Ramachandrarao et al.
6,825,358 B2 11/2004 Afzali-Ardakani et al.
6,884,842 B2 4/2005 Soane et al.
6,887,332 B1 5/2005 Kagan et al.
6,890,624 B1 5/2005 Kambe et al.
6,890,703 B2 5/2005 Hawker et al.
6,908,861 B2 6/2005 Sreenivasan et al.
6,911,400 B2 6/2005 Colburn et al.
6,913,697 B2 7/2005 Lopez et al.
6,924,341 B2 8/2005 Mays et al.
6,926,953 B2 8/2005 Nealey et al.
6,940,485 B2 9/2005 Noolandi
6,946,332 B2 9/2005 Loo et al.
6,949,456 B2 9/2005 Kumar
6,952,436 B2 10/2005 Wimsberger et al.
6,957,608 B1 10/2005 Hubert et al.
6,962,823 B2 11/2005 Empedocles et al.
6,989,426 B2 1/2006 Hu
6,992,115 B2 1/2006 Hawker et al.
6,995,439 B1 2/2006 Hill et al.
6,998,152 B2 2/2006 Uhlenbrock
7,001,795 B2 2/2006 Jiang et al.
7,009,227 B2 3/2006 Patrick et al.
7,030,495 B2 4/2006 Colburn et al.
7,037,738 B2 5/2006 Sugiyama et al.
7,037,744 B2 5/2006 Colburn et al.
7,045,851 B2 5/2006 Black et al.
7,056,455 B2 6/2006 Matyjaszewski et al.
7,056,849 B2 6/2006 Wan et al.
7,060,774 B2 6/2006 Sparrowe et al.
7,066,801 B2 6/2006 Balijepalli et al.
7,077,992 B2 7/2006 Sreenivasan et al.
7,087,267 B2 8/2006 Breen et al.
7,090,784 B2 8/2006 Asakawa et al.
7,112,617 B2 9/2006 Kim et al.
7,115,305 B2 10/2006 Bronikowski et al.
7,115,525 B2 10/2006 Abatchev et al.
7,115,995 B2 10/2006 Wong
7,118,784 B1 10/2006 Xie
7,119,321 B2 10/2006 Quinlan
7,132,370 B2 11/2006 Paraschiv et al.
7,135,144 B2 11/2006 Christel et al.
7,135,241 B2 11/2006 Ferraris et al.
7,135,388 B2 11/2006 Ryu et al.
7,135,523 B2 11/2006 Ho et al.
7,151,209 B2 12/2006 Empedocles et al.
7,163,712 B2 1/2007 Chilkoti et al.
7,166,304 B2 1/2007 Harris et al.
7,172,953 B2 2/2007 Lieber et al.
7,186,613 B2 3/2007 Kirner et al.
7,189,430 B2 3/2007 Ajayan et al.
7,189,435 B2 3/2007 Tuominen et al.
7,190,049 B2 3/2007 Tuominen et al.
7,195,733 B2 3/2007 Rogers et al.
7,202,308 B2 4/2007 Boussand et al.
7,208,836 B2 4/2007 Manning
7,252,791 B2 8/2007 Wasserscheid et al.
7,259,101 B2 8/2007 Zurcher et al.
7,279,396 B2 10/2007 Derderian et al.
7,282,240 B1 10/2007 Jackman et al.
7,291,284 B2 11/2007 Mirkin et al.
7,311,943 B2 12/2007 Jacobson et al.
7,326,514 B2 2/2008 Dai et al.
7,332,370 B2 2/2008 Chang et al.
7,332,627 B2 2/2008 Chandross et al.
7,338,275 B2 3/2008 Choi et al.
7,347,953 B2 3/2008 Black et al.
7,368,314 B2 5/2008 Ufert
7,407,887 B2 8/2008 Guo
7,408,186 B2 8/2008 Merkulov et al.
7,419,772 B2 9/2008 Watkins et al.
7,470,954 B2 12/2008 Lee et al.
7,514,339 B2 4/2009 Yang et al.
7,521,090 B1 4/2009 Cheng et al.
7,553,760 B2 6/2009 Yang et al.
7,569,855 B2 8/2009 Lai
7,585,741 B2 9/2009 Manning
7,592,247 B2 9/2009 Yang et al.
7,605,081 B2 10/2009 Yang et al.
7,632,544 B2 12/2009 Ho et al.
7,655,383 B2 2/2010 Mela et al.
7,658,773 B2 2/2010 Pinnow
7,700,157 B2 4/2010 Bronikowski et al.
7,723,009 B2 5/2010 Sandhu et al.
7,767,099 B2 8/2010 Li et al.
7,888,228 B2 2/2011 Blanchard
7,959,975 B2 6/2011 Millward
7,964,107 B2 6/2011 Millward
8,039,196 B2 10/2011 Kim et al.
8,080,615 B2 12/2011 Millward
8,083,953 B2 12/2011 Millward et al.
8,083,958 B2 12/2011 Li et al.
8,097,175 B2 1/2012 Millward et al.
8,101,261 B2 1/2012 Millward et al.
8,114,300 B2 2/2012 Millward
8,114,301 B2 2/2012 Millward et al.
8,114,306 B2 2/2012 Cheng et al.
8,206,601 B2 * 6/2012 Bosworth et al. 216/11
8,287,749 B2 * 10/2012 Hasegawa et al. 216/41

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,294,139 B2 10/2012 Marsh et al.
8,372,295 B2 2/2013 Millward
8,394,483 B2 3/2013 Millward
8,404,124 B2 3/2013 Millward et al.
8,409,449 B2 4/2013 Millward et al.
8,425,982 B2 4/2013 Regner
8,426,313 B2 4/2013 Millward et al.
2001/0024768 A1 9/2001 Matsuo et al.
2001/0049195 A1 12/2001 Chooi et al.
2002/0055239 A1 5/2002 Tuominen et al.
2002/0084429 A1 7/2002 Craighead et al.
2002/0158342 A1 10/2002 Tuominen et al.
2002/0167117 A1 11/2002 Chou
2003/0010241 A1 1/2003 Fujihira et al.
2003/0034329 A1 2/2003 Chou
2003/0068639 A1 4/2003 Haneder et al.
2003/0077452 A1 4/2003 Guire et al.
2003/0080471 A1 5/2003 Chou
2003/0080472 A1 5/2003 Chou
2003/0091752 A1 5/2003 Nealey et al.
2003/0100822 A1 5/2003 Lew et al.
2003/0108879 A1 6/2003 Klaerner et al.
2003/0143375 A1 7/2003 Noguchi et al.
2003/0157248 A1 8/2003 Watkins et al.
2003/0178707 A1 9/2003 Abbott
2003/0180522 A1 9/2003 DeSimone et al.
2003/0180966 A1 9/2003 Abbott et al.
2003/0185741 A1 10/2003 Matyjaszewski
2003/0222048 A1 12/2003 Asakawa et al.
2003/0235930 A1 12/2003 Bao et al.
2004/0023287 A1 2/2004 Harnack et al.
2004/0028875 A1 2/2004 Van Rijn et al.
2004/0058059 A1 3/2004 Linford et al.
2004/0084298 A1 5/2004 Yao et al.
2004/0124092 A1 7/2004 Black et al.
2004/0125266 A1 7/2004 Miyauchi et al.
2004/0127001 A1 7/2004 Colburn et al.
2004/0142578 A1 7/2004 Wiesner et al.
2004/0159633 A1 8/2004 Whitesides et al.
2004/0163758 A1 8/2004 Kagan et al.
2004/0175628 A1 9/2004 Nealey et al.
2004/0192013 A1 9/2004 Ryu et al.
2004/0222415 A1 11/2004 Chou et al.
2004/0242688 A1 12/2004 Chandross et al.
2004/0254317 A1 12/2004 Hu
2004/0256615 A1 12/2004 Sirringhaus et al.
2004/0256662 A1 12/2004 Black et al.
2004/0265548 A1 12/2004 Ho et al.
2005/0008828 A1 1/2005 Libera et al.
2005/0062165 A1 3/2005 Saenger et al.
2005/0074706 A1 4/2005 Bristol et al.
2005/0079486 A1 4/2005 Abbott et al.
2005/0100830 A1 5/2005 Xu et al.
2005/0120902 A1 6/2005 Adams et al.
2005/0124135 A1 6/2005 Ayazi et al.
2005/0133697 A1 6/2005 Potyrailo et al.
2005/0147841 A1 7/2005 Tavkhelidze
2005/0167651 A1 8/2005 Merkulov et al.
2005/0176256 A1 8/2005 Kudelka
2005/0208752 A1 9/2005 Colburn et al.
2005/0238889 A1 10/2005 Iwamoto et al.
2005/0238967 A1 10/2005 Rogers et al.
2005/0250053 A1 11/2005 Marsh et al.
2005/0271805 A1 12/2005 Kambe et al.
2005/0272341 A1 12/2005 Colburn et al.
2006/0013956 A1 1/2006 Angelescu et al.
2006/0014001 A1 1/2006 Zhang et al.
2006/0024590 A1 2/2006 Sandhu
2006/0030495 A1 2/2006 Gregg
2006/0035387 A1 2/2006 Wagner et al.
2006/0038182 A1 2/2006 Rogers et al.
2006/0046079 A1 3/2006 Lee et al.
2006/0046480 A1 3/2006 Guo
2006/0060863 A1 3/2006 Lu et al.
2006/0062867 A1 3/2006 Choi et al.
2006/0078681 A1 4/2006 Hieda et al.
2006/0097134 A1 5/2006 Rhodes
2006/0105562 A1 5/2006 Yi
2006/0124467 A1 6/2006 Ho et al.
2006/0128165 A1 6/2006 Theiss et al.
2006/0134556 A1 6/2006 Nealey et al.
2006/0137554 A1 6/2006 Kron et al.
2006/0141222 A1 6/2006 Fischer et al.
2006/0141245 A1 6/2006 Stellacci et al.
2006/0154466 A1 7/2006 Lee et al.
2006/0163646 A1 7/2006 Black et al.
2006/0192283 A1 8/2006 Benson
2006/0205875 A1 9/2006 Cha et al.
2006/0211871 A1 9/2006 Dai
2006/0217285 A1 9/2006 Destarac
2006/0228635 A1 10/2006 Suleski
2006/0231525 A1 10/2006 Asakawa et al.
2006/0249784 A1 11/2006 Black et al.
2006/0249796 A1 11/2006 Tavkhelidze
2006/0254440 A1 11/2006 Choi et al.
2006/0255505 A1 11/2006 Sandhu et al.
2006/0257633 A1 11/2006 Inoue et al.
2006/0258159 A1 11/2006 Colburn et al.
2006/0278158 A1 12/2006 Tolbert et al.
2006/0281266 A1 12/2006 Wells
2006/0286305 A1 12/2006 Thies et al.
2006/0286490 A1 12/2006 Sandhu et al.
2006/0292777 A1 12/2006 Dunbar
2007/0020749 A1 1/2007 Nealey et al.
2007/0023247 A1 2/2007 Ulicny et al.
2007/0023805 A1 2/2007 Wells et al.
2007/0045562 A1 3/2007 Parekh
2007/0045642 A1 3/2007 Li
2007/0071881 A1 3/2007 Chua et al.
2007/0072403 A1 3/2007 Sakata
2007/0122749 A1 5/2007 Fu et al.
2007/0122932 A1 5/2007 Kodas et al.
2007/0138131 A1 6/2007 Burdinski
2007/0161237 A1 7/2007 Lieber et al.
2007/0175859 A1 8/2007 Black et al.
2007/0181870 A1 8/2007 Libertino et al.
2007/0183035 A1 8/2007 Asakawa et al.
2007/0194403 A1 8/2007 Cannon et al.
2007/0200477 A1 8/2007 Tuominen et al.
2007/0208159 A1 9/2007 McCloskey et al.
2007/0218202 A1 9/2007 Ajayan et al.
2007/0222995 A1 9/2007 Lu
2007/0224819 A1 9/2007 Sandhu
2007/0224823 A1 9/2007 Sandhu
2007/0227383 A1 10/2007 Decre et al.
2007/0249117 A1 10/2007 Kang et al.
2007/0272951 A1 11/2007 Lieber et al.
2007/0281220 A1 12/2007 Sandhu et al.
2007/0289943 A1 12/2007 Lu et al.
2007/0293041 A1 12/2007 Yang
2008/0032238 A1 2/2008 Lu et al.
2008/0038923 A1 2/2008 Edelstein et al.
2008/0041818 A1 2/2008 Kihara et al.
2008/0047930 A1 2/2008 Blanchet et al.
2008/0064217 A1 3/2008 Horii
2008/0073743 A1 3/2008 Alizadeh et al.
2008/0083991 A1 4/2008 Yang et al.
2008/0085601 A1 4/2008 Park et al.
2008/0093743 A1 4/2008 Yang et al.
2008/0102252 A1 5/2008 Black et al.
2008/0103256 A1 5/2008 Kim et al.
2008/0113169 A1 5/2008 Cha et al.
2008/0164558 A1 7/2008 Yang et al.
2008/0174726 A1 7/2008 Kim
2008/0176767 A1 7/2008 Millward
2008/0193658 A1 8/2008 Millward
2008/0217292 A1 9/2008 Millward et al.
2008/0233297 A1 9/2008 De Jong et al.
2008/0233323 A1 9/2008 Cheng et al.
2008/0257187 A1 10/2008 Millward
2008/0260941 A1 10/2008 Jin
2008/0274413 A1 11/2008 Millward
2008/0286659 A1 11/2008 Millward
2008/0311347 A1 12/2008 Millward et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0315270	A1	12/2008	Marsh et al.	
2008/0318005	A1	12/2008	Millward	
2009/0062470	A1	3/2009	Millward et al.	
2009/0155579	A1	6/2009	Greco et al.	
2009/0200646	A1	8/2009	Millward et al.	
2009/0206489	A1	8/2009	Li et al.	
2009/0212016	A1	8/2009	Cheng et al.	
2009/0218567	A1	9/2009	Mathew et al.	
2009/0236309	A1	9/2009	Millward et al.	
2009/0240001	A1	9/2009	Regner	
2009/0263628	A1	10/2009	Millward	
2009/0267058	A1	10/2009	Namdas et al.	
2009/0274887	A1	11/2009	Millward et al.	
2009/0317540	A1	12/2009	Sandhu et al.	
2010/0092873	A1	4/2010	Sills et al.	
2010/0102415	A1	4/2010	Millward et al.	
2010/0124826	A1	5/2010	Millward et al.	
2010/0137496	A1	6/2010	Millward et al.	
2010/0163180	A1	7/2010	Millward	
2010/0204402	A1	8/2010	Millward et al.	
2010/0279062	A1	11/2010	Millward et al.	
2010/0316849	A1	12/2010	Millward et al.	
2010/0323096	A1	12/2010	Sills et al.	
2011/0232515	A1	9/2011	Millward	
2012/0122292	A1 *	5/2012	Sandhu et al.	438/382
2012/0133017	A1	5/2012	Millward et al.	
2012/0135159	A1 *	5/2012	Xiao et al.	427/534
2012/0164389	A1 *	6/2012	Yang et al.	428/172
2012/0211871	A1 *	8/2012	Russell et al.	257/618
2012/0223053	A1	9/2012	Millward et al.	

FOREIGN PATENT DOCUMENTS

CN	101013662	A	8/2007
EP	0784543		4/2000
EP	1416303	A2	5/2004
EP	1906237		2/2008
EP	1593164	B1	6/2010
JP	11080414	A	3/1999
JP	2003155365		5/2003
JP	2004335962		11/2004
JP	2005008882	A	1/2005
JP	2005029779		3/2005
JP	2006036923	A	2/2006
JP	2006055982	A	3/2006
JP	2006110434		4/2006
JP	2007194175		8/2007
JP	2008036491	A	2/2008
KR	1020060128378		12/2006
KR	20070029762		3/2007
KR	100771886	B1	11/2007
TW	200400990		3/1992
TW	200633925		10/1994
TW	200740602		1/1996
TW	584670	B	4/2004
TW	200419017		10/2004
TW	200511364		3/2005
TW	256110		6/2006
TW	1253456		11/2007
TW	200802421		1/2008
WO	9007575		7/1990
WO	9706013	A1	2/1997
WO	9839645	A1	9/1998
WO	9947570	A1	9/1999
WO	0031183	A1	6/2000
WO	0218080		3/2002
WO	02081372	A2	10/2002
WO	03045840		6/2003
WO	2005122285	A2	12/2005
WO	2006003592		1/2006
WO	2006003594		1/2006
WO	2006076016	A2	7/2006
WO	2006078952	A1	7/2006
WO	2006112887		10/2006
WO	2007001294	A1	1/2007
WO	2007013889	A2	2/2007
WO	2007024241	A2	3/2007
WO	2007024323	A2	3/2007
WO	2007019439	A3	5/2007
WO	2007055041	A1	5/2007
WO	2008055137		5/2008
WO	2008091741	A2	7/2008
WO	2008096335	A2	8/2008
WO	2008097736	A2	8/2008
WO	2008118635	A2	10/2008
WO	2008124219	A2	10/2008
WO	2008130847	A1	10/2008
WO	2008145268	A1	12/2008
WO	2008156977	A2	12/2008
WO	2009099924	A2	8/2009
WO	2009102551	A2	8/2009
WO	2009117238	A2	9/2009
WO	2009117243	A1	9/2009
WO	2009134635	A2	11/2009

OTHER PUBLICATIONS

Hutchison, J. B, et al., "Polymerizable Living Free Radical Initiators as a Platform to Synthesize Functional Networks," Chem. Mater., vol. 17, No. 19, 2005, pp. 4789-4797.

Ikeda, Susumu, et al., "Control of Orientation of Thin Films of Organic Semiconductors by Graphoepitaxy," NanotechJapan Bulletin—vol. 3, No. 3, Dec. 17, 2010/Focus 26-06, NIMS International Center for Nanotechnology Network.

In, Insik, et al., "Side-Chain-Grafted Random Copolymer Brushes as Neutral Surfaces for Controlling the Orientation of Block Copolymer Microdomains in Thin Films," Langmuir, vol. 22, No. 18, 2006, Department of Materials Science and Engineering and Chemical and Biological Engineering, Univ. Of Wisconsin-Madison, pp. 7855-7860.

Ji, Shengxiang, et al., "Generalization of the Use of Random Copolymers to Control the Wetting Behaviors of Block Copolymer Films," Macromolecules, 2008, 41(23): 9098-9103.

Ji, Shengxiang, et al., "Preparation of Neutral Wetting Brushes for Block Copolymer Films from Homopolymer Blends," submitted to Advanced Materials, 20(16): 3054-3060; published online Jul. 7, 2008.

Jun, Y., et al., "Microcontact Printing Directly on the Silicon Surface," Langmuir, 2002, 18(9), pp. 3415-3417, Abstract only.

Karim, Alamgir, et al., "Control of Ordering Kinetics and Morphology Using Zone Annealing of Thin Block Copolymer Films", Abstract submitted for the Mar. 2007 Meeting of The American Physical Society, Nov. 20, 2006.

Kim, Sang Ouk, et al., "Novel Complex Nanostructure from Directed Assembly of Block Copolymers on Incommensurate Surface Patterns," Adv. Mater., 2007, 19, pp. 3271-3275.

Kim, Seung Hyun, et al., "Highly Oriented and Ordered Arrays from Block Copolymers via Solvent Evaporation," Adv. Mater. 2004, 16, No. 3, Feb. 3, pp. 226-231.

Kim, Seung Hyun, et al., "Salt Complexation in Block Copolymer Thin Films," Macromolecules 2006, vol. 39, No. 24, 2006, pp. 8473-8479.

Kim, Seung Hyun, et al., "Solvent-Induced Ordering in Thin Film Diblock Copolymer/Homopolymer Mixtures," Advanced Mater., vol. 16, No. 23-24, Dec. 17, 2004, pp. 2119-2123.

Kim, SH, et al., "In Vitro Release Behavior of Dextran-methacrylate Hydrogels Using Doxorubicin and Other Model Compounds," J Biomater Appl., Jul. 2000; 15(1): 23-46 Abstract only.

Kim, SH, et al., "Synthesis and characterization of Dextran-methacrylate Hydrogels and Structural Study by SEM," J Biomater Res., Mar. 15, 2000; 49(4): 517-27 Abstract only.

Kim, Su-Jin, et al., "Hybrid Nanofabrication Processes Utilizing Diblock Copolymer Nanotemplate Prepared by Self-assembled Monolayer Based Surface Neutralization," J. Vac. Sci. Technol. B26(1), Jan./Feb. 2008, © 2008 American Vacuum Society, pp. 189-194.

Knoll, A., et al., "Phase Behavior in Thin Films of Cylinder-Forming Block Copolymers," Physical Review Letters vol. 89, No. 3 Jul. 2002, The American Physical Society, pp. 035501-1 to 035501-4.

(56) **References Cited**

OTHER PUBLICATIONS

Krishnamoorthy et al., Nonopatterned Self-Assembled Monolayers by Using Diblock Copolymer Micelles as nanometer-Scale Adsorption and Etch Masks, Advanced Materials, 2008, pp. 1-4.
Krishnamoorthy, S., et al., "Nanoscale Patterning with Block Copolymers," Materials Today, vol. 9, No. 9, Sep. 2006, pp. 40-47.
Kuhnline et al., "Detecting thiols in a microchip device using micromolded carbon ink electrodes modified with cobalt phthalocyanine", Analyst, vol. 131, pp. 202-207, (2006).
La, Young-Hye, et al., "Directed Assembly of Cylinder-Forming Block Copolymers into Patterned Structures to Fabricate Arrays of Spherical Domains and Nanoparticles," Chem. Mater, 2007, vol. 19, No. 18, Department of Chemical and Biological Engineering and Center for Nanotechnology, Univ. of Wisconsin, pp. 4538-4544.
La, Young-Hye, et al., "Pixelated Chemically Amplified Resists: Investigation of Material Structure on the Spatial Distribution of Photoacids and Line Edge Roughness," J. Vac. Sci. Technol. B 25(6), Nov./Dec. 2007, American Vacuum Society, pp. 2508-2513.
Laracuente, A.R., et al., "Step Structure and Surface Morphology of Hydrogen-terminated Silicon: (001) to (114)," Surface Science 545, 2003, pp. 70-84.
Lentz, D, et al., "Whole Wafer Imprint Patterning Using Step and Flash Imprint Lithography: A Manufacturing Solution for Sub 100 nm Patterning", SPIE Advanced Lithography Paper, http://molecularimprints.com/NewsEvents/tech_articles/new_articles/SPIE_07_MII_WW_Paper.pdf), Molecular Imprints, Inc., Texas, USA, Feb. 2007, pp. 1-10.
Li, Mingqi, et al., "Block Copolymer Patterns and Templates," Materials Today, vol. 9, No. 9, Sep. 2006, pp. 30-39.
Li, Wai-Kin, et al, "Creation of Sub-20-nm Contact Using Diblock Copolymer on a 300 mm Wafer for Complementary Metal Oxide Semiconductor Applications," J. Vac. Sci. Technol. B 25(6), Nov./Dec. 2007, American Vacuum Society, pp. 1982-1984.
Li, Xue, et al., "Morphology Change of Asymmetric Diblock Copolymer Micellar Films During Solvent Annealing," ScienceDirect, Polymer 48 (2007), pp. 2434-2443.
Lin, Zhiqun, et al., "A Rapid Route to Arrays of Nanostructures in Thin Films," Adv. Mater. 2002, 14 No. 19, Oct. 2, pp. 1373-1376.
Lin-Gibson, Sheng, et al., "Structure—Property Relationships of Photopolymerizable Poly(ethylene glycol) Dimethacrylate Hydrogels," Macromolecules 2005, 38, American Chemical Society, pp. 2897-2902.
Lutolf, M., et al., "Cell-Responsive Synthetic Hydrogels," Adv. Mater., vol. 15, No. 11, Jun. 2003, pp. 888-892.
Lutolf, M.P., et al, "Synthetic Biomaterials as Instructive Extracellular Microenvironments for Morphogenesis in Tissue Engineering," Nature Biotechnology, 23, 47-55 (2005), Abstract only.
Malkoch, M., et al., "Synthesis of Well-defined Hydrogel Networks Using Click Chemistry," Chem. Commun., 2006, The Royal Society of Chemistry, pp. 2774-2776.
Mansky, P., et al., "Controlling Polymer-Surface Interactions with Random Copolymer Brushes," Science, vol. 275, Mar. 7, 1997, pp. 1458-1460.
Martens, P., et al., "Characterization of Hydrogels Formed from Acrylate Modified Poly(vinyl alcohol) Macromers," Polymer, Vol. 41, Issue 21, Oct. 2000, pp. 7715-7722, Abstract only.
Matsuda, T., et al., "Photoinduced Prevention of Tissue Adhesion," Asaio J, Jul.-Sep. 1992; 38(3): M154-7, Abstract only.
Maye, M. A., et al., "Chemical Analysis Using Force Microscopy," Journal of Chemical Education, vol. 79, No. 2, Feb. 2002, Dept. of Chemistry, State Univ. of New York at Binghamton, USA, pp. 207-210.
Metters, A., et al., "Network Formation and Degradation Behavior of Hydrogels Formed by Michael-Type Addition Reactions," Biomacromolecules 2005, 6, 2005, pp. 290-301.
Meyer, E., et al., "Controlled Dewetting Processes on Microstructured Surfaces—a New Procedure for Thin Film Microstructuring," Macromollecular Mater. Eng., 276/277, 2000, Institute of Polymer Research Dresden, pp. 44-50.
Mezzenga, R., et al., "On the Role of Block Copolymers in Self-Assembly of Dense Colloidal Polymeric Systems," Langmuir 2003, vol. 19, No. 20, 2003, American Chemical Society, pp. 8144-8147.
Mindel, J., et.al., "A Study of Bredig Platinum Sols", The Chemical Laboratories of New York University, received Jun. 10, 1943, vol. 65 pp. 2112.
Naito, K., et al., "2.5-Inch Disk Patterned Media Prepared by an Artificially Assisted Self-Assembling Method," IEEE Transactions on Magnetics, vol. 38, No. 5, Sep. 2002, pp. 1949-1951.
Nealey, P. F., et al., "Self-Assembling Resists for Nanolithography", |Proceedings of the IEEE International Electron Devices Meeting, IEDM Technical Digest, 356-359 (2005).
Nguyen, K. T., et al., "Photopolymerizable Hydrogels for Tissue Engineering Applications," Biomaterials 23, 2002, pp. 4307-4314.
Nishikubo, T., "Chemical Modification of Polymers via a Phase-Transfer Catalyst or Organic Strong Base," American Chemical Society Symposium Series, 1997, American Chemical Society, pp. 214-230.
Niu, Sanjun, et al., "Stability of Order in Solvent-Annealed Block Copolymer Thin Films," Macromolecules, vol. 36, No. 7, 2003, Univ. of Nebraska, USA, pp. 2428-2440, (web release date: Mar. 13, 2003) (http://digitalcommons.uni.edu/cgi/viewcontent.cgi?article+1005&contect=chemeng_nanotechnology).
Olayo-Valles, R., et al., "Large Area Nanolithographic Templates by Selective Etching of Chemically Stained Block Copolymer Thin Films," J. Mater. Chem, 2004, 14, The Royal Society of Chemistry, pp. 2729-2731.
Parejo, P. G., et al., "Highly Efficient UV-absorbing Thin-film Coatings for Protection of Organic Materials Against Photodegradation," J. Mater. Chem, 2006, 16, The Royal Society of Chemistry, pp. 2165-2169.
Park et al., High-Aspect-Ratio Cylindrical Nanopore Arrays and Their Use for Templating Titania Nanoposts, Advanced Materials, vol. 20, pp. 738-742, 2008.
Park, Cheolmin, et al., "Enabling Nanotechnology with Self Assembled Block Copolymer Patterns," Polymer 44, 2003, pp. 6725-6760.
Park, Dae-Ho, "The Fabrication of Thin Films with Nanopores and Nanogrooves from Block Copolymer Thin Films on the Neutral Surface of Self-assembled Monolayers," Nanotechnology 18, 2007, 355304, IIOP Publishing LTD, UK, pp. 1-7.
Park, M., et al., "Block Copolymer Lithography: Periodic Arrays of 1011 Holes in 1 Square Centimeter," Science, vol. 276, No. 5317, May 30, 1997, pp. 1401-1404.
Electronegativity—<http://www.princeton.edu/~achaney/tmve/wiki100k/docs/Electronegativity.html> website, visited Aug. 28, 2013, 1 page.
Kim et al., Self-assembled Hydrogel Nanoparticles Composed of Dextran and Poly (ethylene glycol) Macromer, Int J Pharm., vol. 205, No. 1-2, (Sep. 15, 2000), pp. 109-116, abstract only.
Xiao et al., Graphoepitaxy of Cylinder-forming Block Copolymers for Use as Templates to Pattern Magnetic Metal Dot Arrays, Nanotechnology 16, IPO Publishing Ltd, UK (2005), pp. S324-S329.
Ali, H. A., et al., Properties of Self-assembled ZnO Nanostructures, Solid-State Electronics 46 (2002), 1639-1642.
Bae, Joonwon, "Surface Modification Using Photo-Crosslinkable Random Copolymers", Abstract submitted for the Mar. 2006 meeting of The American Physical Society, submitted Nov. 30, 2005. (Accessed via the Internet [retrieved on Apr. 5, 2010], URL: http://absimage.aps.org/image/MWS_MAR06-2005-003641.pdf).
Balsara, C., et al, CPIMA, IRG Technical Programs, Synthesis and application of Nanostructured Materials, Leland Stanford Junior Univ., 2006, http://www.stanford.edu/group/cpima/irg/irg_1.htm, printed Jul. 1, 2009.
Bang, J., "The Effect of Humidity on the Ordering of Tri-block Copolymer Thin Films," Abstract submitted for the Mar. 2007 meeting of The American Physical Society, submitted Nov. 20, 2006.
Bass, R. B., et al., "Microcontact Printing with Octadecanethiol", Applied Surface Science, 226(4), pp. 335-340, Apr. 2004, http://www.ece.virginia.edu/UVML/sis/Papers/rbbpapers/assoct.pdf.
Bearinger, J. P., et al., "Chemisorbed Poly(propylene sulphide)-based Copolymers Resist Biomolecular Interactions," Nature Materials 2, 259-264, 2003, (published online Mar. 23, 2003).

(56) **References Cited**

OTHER PUBLICATIONS

Berry, B. C., et al., "Orientational Order in Block Copolymer Films Zone Annealed Below the Order-Disorder Transition Temperature," Nano Letters vol. 7, No. 9 Aug. 2007, Polymers Division, Nat'l. Inst. of Standards and Technology, Maryland, USA, pp. 2789-2794, (published on Web Aug. 11, 2007).
Berry, B. C., et al., "Effects of Zone Annealing on Thin Films of Block Copolymers", National Institute of Standard and Technology, Polymers Division, Maryland, USA, 2007, 2 pages.
Black, C .T., et al., "Integration of Self Assembly for Semiconductor Microelectronics," IEEE 2005 Custom Integrated Circuits Conference, IBM T.J. Watson Research Center, pp. 87-91.
Black, C. T., "Polymer Self-Assembly as a Novel Extension to Optical Lithography," ACSNano, vol. 1, No. 3, 2007, American Chemical Society, pp. 147-150.
Black, C. T., et al., "High-Capacity, Self-Assembled Metal-Oxide-Semiconductor Decoupling Capacitors," IEEE Electron Device Letters, vol. 25, No. 9, Sep. 2004, pp. 622-624.
Black, C. T., et al., "Self Assembly in Semiconductor Microelectronics: Self-Aligned Sub-Lithographic Patterning Using Diblock Copolymer Thin Films," Proc. of SPIE, vol. 6153, 615302 (2006).
Black, C. T., et al., Polymer Self Assembly in Semiconductor Microelectronics, IBM J. Res. & Dev. vol. 51, No. 5, Sep. 2007, pp. 605-633.
Botelho Do Rego, A. M, et al., "Diblock Copolymer Ultrathin Films Studied by High Resolution Electron Energy Loss Spectroscopy," Surface Science, 482-485 (2001), pp. 1228-1234.
Brydson, R. M., et al. (chapter authors), "Generic Methodologies for Nanotechnology: Classification and Fabrication", Nanoscale Science and Technology, edited by R.W. Kelsall, et al., 2005 John Wiley & Sons, Ltd., (published online: Dec. 20, 2005) (http://www3.interscience.wiley.com/cgi-bin/summary/112217550/SUMMARY).
Bulpitt, P., et al, "New Strategy for Chemical Modification of Hyaluronic Acid: Preparation of Functionalized Derivatives and Their Use in the Formation of Novel Biocompatible Hydrogels," Journal of Biomedical Materials Research, vol. 47, Issue 2, pp. 152-169, Published online Aug. 13, 1999, Abstract only.
Canaria, C. A., et al., "Formation and Removal of Alkylthiolate Self-Assembled Monolayers on Gold in Aqueous Solutions", Lab Chip 6, 289-295 (2006), http://www.rsc.org/publishing/journals/LC/article.asp?doi=b51066c) (Abstract).
Candau, F., et al., "Synthesis and Characterization of Polystyrene-poly(ethylene oxide) Graft Copolymers," Polymer, 1977, vol. 18, pp. 1253-1257.
Cavicchi, K. A., et al., "Solvent Annealed Thin Films of Asymmetric Polyisoprene-Polylactide Diblock Copolymers," Macromolecules 2007, vol. 40, 2007, Univ. of Massachusetts, pp. 1181-1186.
Chandekar, A., et al., "Template-Directed Adsorption of block Copolymers on Alkanethiol-Patterned Gold Surfaces," (circa 2006), http://www.nano.neu.edu/industry/industry_showcase/industry_day/documents/Chandekar.pdf) (Powerpoint template for scientific posters (Swarthmore College)).
Chang, Li-Wen, "Diblock Copolymer Directed Self-Assembly for CMOS Device Fabrication," Proc. of SPIE, vol. 6156, 2006, 615611-1 to 615611-6.
Chang, Li-Wen, "Experimental Demonstration of Aperiodic Patterns of Directed Self-Assembly of Block Copolymer Lithography for Random Logic Circuit Layout," IEEE International Electron Devices Meeting (IEDM), paper 33.2, Dec. 6-8, San Francisco, 2010, pp. 33.2.1-33.2.4.
Cheng, J. Y., et al., "Rapid Directed Self Assembly of Lamellar Microdomains from a Block Copolymer Containing Hybrid," Applied Physics Letters, 91, 143106-143106-3 (2007).
Cheng, J. Y., et al., "Self-Assembled One-Dimensional Nanostructure Arrays," Nano Letters, vol. 6, No. 9, 2006, pp. 2099-2103.
Cheng, J. Y., et al., "Templated Self-Assembly of Block Copolymers: Effect of Substrate Topography," Adv. Mater. 2003, vol. 15, No. 19, pp. 1599-1602.
Choi, H. J., et al., "Magnetorheology of Synthesized Core-Shell Structured Nanoparticle," IEEE Transactions on Magnetics, vol. 41, No. 10, Oct. 2005, pp. 3448-3450.
Daoulas Kostas CH., et al., "Fabrication of Complex Three-Dimensional Nanostructures from Self-Assembling Block Copolymer Materials on Two-Dimensional Chemically Patterned Templates with Mismatched Symmetry," Physical Review Letters 96, week ending Jan. 27, 2006, pp. 036104-1-3.
Darling, S. B., "Directing the Self-assembly of Block Copolymers," Progress in Polymer Science, vol. 32, No. 10, Sep. 28, 2007, pp. 1152-1204.
Desai, Dr. Trejal A., et al., "Engineered Silicon Surfaces for Biomimetic Interfaces," Business Briefing: Medical Device Manufacturing & Technology, 2002.
Edwards, E. W., et al., "Mechanism and Kinetics of Ordering in Diblock Copolymer Thin Films on Chemically Nanopatterned Substrates," Journal of Polymer Science: Part B Polymer Physics, vol. 43, 3444-3459, 2005.
Edwards, E. W., et al., "Precise Control over Molecular Dimensions of Block-Copolymer Domains Using the Interfacial Energy of Chemically Nanopatterned Substrates," Advanced Mater., 16, No. 15, Aug. 4, 2004, pp. 1315-1319.
Elisseeff, J., et al., "Photoencapsulation of Chondrocytes in Poly(ethylene oxide)-based Semi-interpenetrating Networks," Journal of Biomedical Materials Research, 51(2): 164-171, Aug. 2000, Abstract only.
Fasolka, M. J. et al., "Morphology of Ultrathin Supported Diblock Copolymer Films: Theory and Experiment," Macromolecules 2000, vol. 33, No. 15, pp. 5702-5712.
Fukunaga, K., et al., "Self-Assembly of Block Copolymer Thin Films Having a Half-Domain-Spacing Thickness: Nonequilibrium Pathways to Achieve Equilibrium Brush Layers Parallel to Substrate," Macromolecules vol. 39, Aug. 2006, pp. 6171-6179.
Gates, B. D., et al., "Unconventional Nanofabrication," Annu. Rev. Mater. Res. 2004, 34:339-72.
Ge, Zhenbin, et al., "Thermal Conductance of Hydrophilic and Hydrophobic Interfaces," PRL 96, 186101-1-186101-4, The American Physical Society, week ending May 12, 2006.
Gelest Inc., "Silane Coupling Agents: Connecting Across Boundaries," v2.0, 2006, pp. 1-56.
Genua, A., et al., "Functional Patterns Obtained by Nanoimprinting Lithography and Subsequent Growth of Polymer Brushes," Nanotechnology, 18, (2007), IOP Publishing Ltd., pp. 1-7.
Gillmor, S. D., et al., "Hydrophilic/Hydrophobic Patterned Surfaces as Templates for DNA Arrays," Langmuir 2000, vol. 16, No. 18, 2000, pp. 7223-7228.
Gudipati, C. S., et al., "Hyperbranched Fluoropolymer and Linear Poly(ethylene glycol) Based Amphiphilic Crosslinked Networks as Efficient Antifouling Coatings: An Insight into the Surface Compositions, Topographies, and Morphologies," Journal of Polymer Science Part A: Polymer Chemistry, vol. 42, (2004), pp. 6193-6208.
Guo, Kai, et al., Abstract of "Synthesis and Characterization of Novel Biodegradable Unsaturated Poly(ester amide)/Poly(ethylene glycol) Diacrylate Hydrogels", Journal of Polymer Science Part A: Polymer Chemistry, vol. 43, Issue 17, 2005 Wiley Periodicals, Inc., pp. 3932-3944.
Hamley, I. W., "Introduction to Block Copolymers", Developments in Block Copolymers Science and Technology, John Wiley & Sons, Ltd., 2004, pp. 1-29.
Hammond, M. R., et al., "Temperature Dependence of Order, Disorder, and Defects in Laterally Confined Diblock Copolymer Cylinder Monolayers," Macromolecules, vol. 38, Jul. 2005; American Chemical Society, p. 6575-6585.
Harrison, C., et al., "Layer by Layer Imaging of Diblock Copolymer Films with a Scanning Electron Microscope," Polymer, vol. 39, No. 13, 1998, pp. 2733-2744.
Hawker, C. J., et al., "Facile Synthesis of Block Copolymers for Nanolithographic Applications," Polymer Reprints, American Chemical Society (2005).
Hawker, C. J., et al., Abstract for "Improving the Manufacturability and Structural Control of Block Copolymer Lithography," Abstracts of Papers, 232nd ACS National Meeting, San Francisco, CA, Sep. 10-14, 2006.

(56) **References Cited**

OTHER PUBLICATIONS

He et al., "Self-Assembly of Block Copolymer Micelles in an Ionic Liquid," J. Am. Chem. Soc. 2006, 128, pp. 2745-2750.
Helmbold, A., et al., "Optical Absorption of Amorphous Hydrogenated Carbon Thin Films," Thin Solid Films 283 (1996) pp. 196-203.
Hermans, T. M., et al., "Application of Solvent-Directed Assembly of Block Copolymers to the Synthesis of Nanostructured Materials with Low Dielectric Constants", Angewandte Chem. Int. Ed., vol. 45, Issue 40, Oct. 13, 2006, pp. 6648-6652.
Park, Seung Hak, et al., "Block Copolymer Multiple Patterning Integrated with Conventional ArF Lithography," Soft Matter, 2010, 6, Royal Society of chemistry, pp. 120-125.
Park, Sung Chan, et al., "Controlled Ordering of Block Copolymer Thin Films by the Addition of Hydrophilic Nanoparticles," Macromolecules 2007, vol. 40, No. 22, American Chemical Society, pp. 8119-8124.
Peng, J., et. al., "Development of Nanodomain and Fractal Morphologies in Solvent Annealed Block copolymer Thin Films," Macromol. Rapid Commun. 2007, 28, pp. 1422-1428.
Peters, R. D., et al., "Combining Advanced Lithographic Techniques and Self-assembly of Thin Films of Diblock Copolymers to Produce Templates for Nanofabrication," J. Vac. Sci. Technol. B, vol. 18, No. 6, Nov./Dec. 2000, American Vacuum Society, pp. 3530-3532.
Peters, R. D., et al., "Morphology of Thin Films of Diblock Copolymers on Surfaces Micropatterned with Regions of Different Interfacial Energy," Macromolecules, vol. 35, No. 5, 2002, American Chemical Society, pp. 1822-1834.
Potemkin, Igor I., et al., "Effect of the Molecular Weight of AB Diblock Copolymers on the Lamellar Orientation in Thin Films: Theory and Experiment," Macromol. Rapid Commun., 2007, 28, pp. 579-584.
Resnick, D. J., et al., "Initial Study of the Fabrication of Step and Flash Imprint Lithography Templates for the Printing of Contact Holes," Microlith., Microfab., Microsyst., vol. 3, No. 2, Apr. 2004, Society of Photo-Optical Instrumentation Engineers, pp. 316-321.
Rogers, J. A., "Slice and Dice, Peel and Stick: Emerging Methods for Nanostructure Fabrication," ACS Nano, vol. 1, No. 3, 2007, pp. 151-153.
Ruiz, R., et al., "Density Multiplication and Improved Lithography by Directed Block Copolymer Assembly," Science, vol. 321, Aug. 15, 2008, pp. 936-939.
Ryu, Du Yeol, et al., "Surface Modification with Cross-Linked Random Copolymers: Minimum Effective Thickness," Macromolecules, vol. 40, No. 12, 2007, American Chemical Society, pp. 4296-4300.
Sang et al., "Epitaxial self-assembly of block copolymers on lithographically defined nanopatterned substrates", Nature, vol. 24, pp. 411-414, (Jul. 2003).
Saraf, Ravi R., et al., "Spontaneous Planarization of Nanoscale Phase Separated Thin Film," Applied Physics Letters, vol. 80, No. 23, Jun. 10, 2002, American Institute of Physics, pp. 4425-4427.
Sawhney, A. S., et al., "Bioerodible Hydrogels Based on Photopolymerized Poly(ethylene glycol)-co-poly(a-hydroxy acid) Diacrylate Macromers," Macromolecules 1993, 26, American Chemical Society, pp. 581-587, Abstract only.
Segalman, R. A., "Patterning with Block Copolymer Thin Films," Materials Science and Engineering R 48 (2005), Elsevier B. V., pp. 191-226.
Shahrjerdi, D., et al., "Fabrication of Ni Nanocrystal Flash Memories Using a Polymeric Self-Assembly Approach," IEEE Electron Device Letters, vol. 28, No. 9, Sep. 2007, pp. 793-796.
Sharma, S. et al., "Ultrathin Poly(ethylene glycol) Films for Silicon-based Microdevices," Applied Surface Science, 206 (2003), Elsevier Science B.V., pp. 218-229.
Sigma-Aldrich, 312-315Tutorial regarding Materials for Lithography/Nanopatterning, http://www.sigmaaldrich.com/Area_of Interest/Chemistry/Materials_Science/Micro_and_Nanoelectronic website, retrieved Aug. 27, 2007.
Sivaniah, E., et al., "Observation of Perpendicular Orientation in Symmetric Diblock Copolymer Thin Films on Rough Substrates," Macromolecules 2003, 36, American Chemical Society, pp. 5894-5896.
Sivaniah, et al., "Symmetric Diblock Copolymer Thin Films on Rough Substrates, Kinetics and Structure Formation in Pure Block Copolymer Thin Films," Macromolecules 2005, 38, American Chemical Society, pp. 1837-1849.
Solak, H. H., "Nanolithography with Coherent Extreme Ultraviolet Light," Journal of Physics D: Applied Physics, 2006, IOP Publishing Ltd., UK, pp. R171-188.
Srinvivasan, C., et al., "Scanning Electron Microscopy of Nanoscale Chemical Patterns," ACS Nano, vol. 1, No. 3, pp. 191-201, 2007.
Stoykovich, M. P., et al., "Directed Assembly of Block Copolymer Blends into Nonregular Device-Oriented Structures," Science, vol. 308, Jun. 3, 2005, pp. 1442-1446.
Stoykovich, M. P., et al., "Directed Self-Assembly of Block Copolymers for Nanolithography: Fabrication of Isolated Features and Essential Integrated Circuit Geometries," ACS Nano, vol. 1, No. 3, 2007, pp. 168-175.
Sundrani, D., et al., "Guiding Polymers to Perfection: Macroscopic Alignment of Nanoscale Domains," Nano Lett., vol. 4, No. 2, 2004, American Chemical Society, pp. 273-276.
Sundrani, D., et al., "Hierarchical Assembly and Compliance of Aligned Nanoscale Polymer Cylinders in Confinement," Langmuir 2004, vol. 20, No. 12, 2004, American Chemical Society, pp. 5091-5099.
Tang et al., Evolution of Block Copolymer Lithography to Highly Ordered Square Arrays, Science, vol. 322, No. 5900, Sep. 25, 2008, pp. 429-432.
Trimbach et al., "Block Copolymer Thermoplastic Elastomers for Microcontact Printing," Langmuir, 2003, vol. 19, p. 10957.
Truskett, V. M., et. al., "Trends in Imprint Lithography for Biological Applications," TRENDS in Biotechnology, vol. 24, No. 7, Jul. 2006, pp. 312-315.
Tseng et al., Enhanced Block Copolymer Lithography Using Sequential Infiltration Synthesis, The Journal of Physical Chemistry, vol. 115, No. 36, Sep. 15, 2011, 15 pages.
Van Poll, M. L., et al., "a Self-Assembly Approach to Chemical Micropatterning of Poly(dimethylsiloxane)," Angew. Chem. Int. Ed. 2007, 46, pp. 6634-6637.
Wang, C., et al., "One Step Fabrication and characterization of Platinum Nanopore Electrode Ensembles formed via Amphiphilic Block Copolymer Self-assembly," Electrochimica Acta 52 (2006), pp. 704-709.
Wathier, M., et al., "Dendritic Macromers as in Situ Polymerizing Biomaterials for Securing Cataract Incisions," J. Am. Chem. Soc., 2004, 126 (40), pp. 12744-12745, Abstract only.
Winesett, D.A., et al., "Tuning Substrate Surface Energies for Blends of Polystyrene and Poly(methyl methacrylate)," Langmuir 2003, 19, American Chemical Society, pp. 8526-8535.
WIPF, "Handbook of Reagents for Organic Synthesis", 2005, John Wiley & Sons Ltd., p. 320.
Wu, C.Y., et al., "Self-Assembled Two-Dimensional Block Copolymers on Pre-patterned Templates with Laser Interference Lithography," IEEE, 2007, pp. 153-154.
Xu, Ting, et al., "The Influence of Molecular Weight on Nanoporous Polymer Films," Polymer 42, Elsevier Science Ltd., (2001) pp. 9091-9095.
Yamaguchi, Toru, et al., "Two-dimensional Arrangement of Vertically Oriented Cylindrical Domains of Diblock Copolymers Using Graphoepitaxy with Artificial Guiding Pattern Layout," Microprocesses and Nanotechnology, 2007, Conference date Nov. 5-8, 2007, pp. 434-435.
Yan, Xiaohu, et al., "Preparation and Phase Segregation of Block Copolymer Nanotube Multiblocks," J. Am. Chem. Soc., vol. 126, No. 32, 2004, American Chemical Society, pp. 10059-10066.
Yang, Xiao M., et al., "Guided Self-Assembly of Symmetric Diblock Copolymer Films on Chemically Nanopatterned Substrates," Macromolecules 2000, vol. 33, No. 26, 2000, American Chemical Society, pp. 9575-9582.

(56) **References Cited**

OTHER PUBLICATIONS

Yang, Xiaomin, et al., "Nanoscopic Templates Using Self-assembled Cylindrical Diblock Copolymers for Patterned Media," J. Vac. Sci. Technol. B 22(6), Nov./Dec. 2004, American Vacuum Society, pp. 3331-3334.
Yurt, Serkan, et al., "Scission of Diblock Copolymers into Their Constituent Blocks," Macromolecules 2006, vol. 39, No. 5, 2006, American Chemical Society, pp. 1670-1672.
Zhang, Mingfu, et al., "Highly Ordered Nanoporous Thin Films from Cleavable Polystyrene-block-poly(ethylene oxide),"Adv. Mater. 2007, 19, pp. 1571-1576.
Zhang, Yuan, et al., "Phase Change Nanodot Arrays Fabricated Using a Self-Assembly Diblock Copolymer Approach," Applied Physics Letter, 91, 013104, 2007, American Institute of Physics, pp. 013104 to 013104-3.
Arshady et al., The Introduction of Chloromethyl Groups into Styrene-based Polymers, 1, Makromol. Chem., vol. 177, 1976, p. 2911-2918.
Xu et al., Electric Field Alignment of Symmetric Diblock Copolymer Thin Films, Department of Polymer Science and Engineering, University of Massachusetts, 5 pages (2003).
Xu et al., Interfacial Interaction Dependence of Microdomain Orientation in Diblock Copolymer Thin Films, Macromolecules, vol. 38, pp. 2802-2805 (2005).
Xu, F.J., et al., "Surface-Initiated Atom Transfer Radical Polymerization from Halogen-Terminated Si(111) (Si-X, X=Cl, Br) Surfaces for the Preparation of Well-Defined Polymer-Si Hybrids," Langmuir, vol. 21, No. 8, pp. 3221-3225, 2005.
Yamaguchi et al., Resist-Pattern Guided Self-Assembly of Symmetric Diblock Copolymer, Journal of Photopolymer Science and Technology, vol. 19, No. 3, pp. 385-388 (2006).
Yang et al., Covalently Attached Graft Polymer Monolayer on Organic Polymeric Substrate via Confined Surface Inhibition Reaction, Journal of Polymer Science-A—Polymer Chemistry Edition, Sep. 28, 2006, pp. 745-755, vol. 45, Issue 5.
Yu et al., Contact Printing Beyond Surface Roughness: Liquid Supramolecular Nanostamping, Advanced Materials, vol. 19, 2007, pp. 4338-4342.
Zaumseil et al., "Three-Dimensional and Multilayer Nanostructures Formed by Nanotransfer Printing," Nano Letters, 2003, vol. 3, No. 9, pp. 1223-1227.
Zehner, Robert W., et al., "Selective Decoration of a Phase-Separated Diblock Copolymer with Thiol-Passivated Gold Nanocrystals," Langmuir, vol. 14, No. 2, pp. 241-243, Jan. 20, 1998.
Zhang et al., "Self-Assembled Monolayers of Terminal Alkynes on Gold," J. Am. Chem. Soc., vol. 129, No. 16, pp. 4876-4877, 2007.
Zhao et al., Colloidal Subwavelength Nanostructures for Antireflection Optical Coatings, Optics Letters, vol. 30, No. 14, pp. 1885-1887 (2005).
Zhou et al., Nanoscale Metal/Self-Assembled Monolayer/Metal Heterostructures, American Institute of Physics, pp. 611-613 (1997).
Zhu, X.Y., et al., "Grafting of High-Density Poly(Ethylene Glycol) Monolayers on Si(111)," Langmuir, vol. 17, pp. 7798-7803, 2001.
Zhu, X.Y., et al., "Molecular Assemblies on Silicon Surfaces via Si-O Linkages," Langmuir, vol. 16, pp. 6766-6772, 2000.
Asakawa et al., Fabrication of Subwavelength Structure for Improvement in Light-Extraction Efficiency of Light-Emitting Devices Using a Self-Assembled Pattern of Block Copolymer, http://www.research.ibm.com/journal/rd/515/black.html, IBM Journal of Research and Development, vol. 51, No. 5, 2007.
Black et al., Integration of Self-Assembled Diblock Copolymers for Semiconductor Capacitor Fabrication, Applied Physics Letters, vol. 79, No. 3, pp. 409-411 (2001).
Black et al., Polymer Self Assembly in Semiconductor Microelectronics, IBM J. Res. & Dev. vol. 51, No. 5, Sep. 2007, pp. 605-633.
Black, C.T., "Self-aligned self-assembly of multi-nanowire silicon field effect transistors," Appl. Phys. Lett., vol. 87, pp. 163116-1 through 163116-3, 2005.
Black, Charles T., et al., "Nanometer-Scale Pattern Registration and Alignment by Directed Diblock Copolymer Self-Assembly," IEEE Transactions on Nanotechnology, vol. 3, No. 3, pp. 412-415, Sep. 2004.
Cha et al., Biomimetic Approaches for Fabricating High-Density Nanopatterned Arrays, Chem. Mater. vol. 19, 2007, pp. 839-843.
Chen et al., Highly Ordered Arrays of Mesoporous Silica Nanorods with Tunable Aspect Ratios from Block Copolymer Thin Films, Advanced Materials, vol. 20, pp. 763-767, 2008.
Cho et al., Nanoporous Block Copolymer Micelle/Micelle Multilayer Films with Dual Optical Properties, J. Am. Chem. Soc., vol. 128, No. 30, pp. 9935-9942 (2006).
Clark et al., "Selective Deposition in Multilayer Assembly: SAMs as Molecular Templates," Supramolecular Science, vol. 4, pp. 141-146, (1997).
Erlandsson, Mikael, et al., "Metallic Zinc Reduction of Disulfide Bonds between Cysteine Residues in Peptides and Proteins," International Journal of Peptide Research and Therapeutics, vol. 11, No. 4, pp. 261-265, Dec. 2005.
Fasolka et al., Block Copolymer Thin Films: Physics and Applications1, Annual Review, vol. 31, pp. 323-355 (2001).
Gates, "Nanofabrication with Molds and Stamps," Materials Today, pp. 44-49, (Feb. 2005).
Grubbs, Hybrid Metal-Polymer Composites from Functional Block Copolymers, Journal of Polymer Science: Part A: Polymer Chemistry, vol. 43, pp. 4323-4336 (2005).
Guarini et al., Nanoscale Patterning Using Self-Assembled Polymers for Semiconductor Applications, J. Vac. Sci. Technol. B 19(6), pp. 2784-2788, Nov./Dec. (2001).
Hadziioannou, Semiconductor Block Copolymers for Self-Assembled Photovoltaic Devices, MRS Bulletin, pp. 456-460 (2002).
Hamers, Robert J., "Passivation and activation: How do monovalent atoms modify the reactivity of silicon surfaces? A perspective on the article, 'The mechanism of amine formation on Si(100) activated with chlorine atoms,'" Surface Science, vol. 600, pp. 3361-3362, 2006.
Hayward et al., Crosslinked Poly(styrene)-block-Poly(2-vinylpyridine) Thin Films as Swellable Templates for Mesostructured Silica and Titania, Advanced Materials, vol. 17, 2005, pp. 2591-2595.
Helmuth, Jo A., et al., "High-Speed Microcontact Printing," J. Am. Chem. Soc., vol. 128, No. 29, pp. 9296-9297, 2006.
Horiuchi et al., Three-Dimensional Nanoscale Alignment of Metal Nanoparticles Using Block Copolymer Films as Nanoreactors, Langmuir, vol. 19, pp. 2963-2973 (2003).
Huang et al., "Using Surface Active Random Copolymers to Control the Domain Orientation in Diblock Copolymer Thin Films," Macromolecules, 1998, 31, 7641-7650.
Hur et al., "Nanotransfer printing by use of noncovalent surface forces: Applications to thin-film transistors that use single-walled carbon nanotube networks and semiconducting polymers," Applied Physics Letters, vol. 85, No. 23, Dec. 6, 2004, pp. 5730-5732.
International Search Report for International Application No. PCT/US20091062117 dated Jun. 1, 2010, 3 pages.
Ji et al., Molecular Transfer Printing Using Block Copolymers, ACS Nano, vol. 4, No. 2, pp. 599-609, 2010.
Jiang, Xingyu, et al., "Electrochemical Desorption of Self-Assembled Monolayers Noninvasively Releases Patterned Cells from Geometrical Confinements," J. Am. Chem. Soc., vol. 125, No. 9, pp. 2366-2367, 2003.
Johnson, Daniel L., et al., "Probing the stability of the disulfide radical intermediate of thioredoxin using direct electrochemistry," Letters in Peptide Science, vol. 10, pp. 495-500, 2003.
Jun, Yongseok, et al., "Microcontact Printing Directly on the Silicon Surface," Langmuir, vol. 18, No. 9, pp. 3415-3417, 2002.
Jun, Yongseok, et al., "Patterning protein molecules on poly(ethylene glycol) coated Si(111)," Biomaterials, vol. 25, pp. 3503-3509, 2004.
Kavakli et al., Single and Double-Layer Antireflection Coatings on Silicon, Turk J Phys, vol. 26, pp. 349-354 (2002).
Kim et al., "Epitaxial self-assembly of block copolymers on lithographically defined nanopatterned substrates", Nature, vol. 24, pp. 411-414, (Jul. 2003).

(56) **References Cited**

OTHER PUBLICATIONS

Krishnamoorthy et al., Block Copolymer Micelles as Switchable Templates for Nanofabrication, Languir, vol. 22, No. 8, Mar. 17, 2006, pp. 3450-3452.
Li, Yong, et al., "A Method for Patterning Multiple Types of Cells by Using Electrochemical Desorption of Self-Assembled Monolayers within Microfluidic Channels," Angew. Chem. Int. Ed., vol. 46, pp. 1094-1096, 2007.
Liu et al., Pattern Transfer Using Poly(styrene-block-methyl methacrylate) Copolymer Films and Reactive Ion Etching, J. Vac. Sci. Technol. B vol. 25, No. 6, Nov./Dec. 2007, pp. 1963-1968.
Loo et al., "Additive, nanoscale patterning of metal films with a stamp and a surface chemistry mediated transfer process: Applications in plastic electronics," Applied Physics Letters, vol. 81, No. 3, Jul. 15, 2002, pp. 562-564.
Lopes et al., Hierarchical Self-Assembly of Metal Nanostructures on Diblock Copolymer Scaffolds, Nature, vol. 414, Dec. 13, 2001, pp. 735-738.
Lutz, Jean-Francois, "1,3-Dipolar Cycloadditions of Azides and Alkynes: A Universal Ligation Tool in Polymer and Materials Science," Angew. Chem. Int. Ed., vol. 46, pp. 1018-1025, 2007.
Malenfant et al., Self-Assembly of an Organic-Inorganic Block Copolymer for Nano-Ordered Ceramics, Nature Nanotechnology, vol. 2, pp. 43-46 (2007).
Niu, Sanjun, et al., "Selective assembly of nanoparticles on block copolymer by surface modification," Nanotechnology, vol. 18, pp. 1-4, 2007.
Park et al., Fabrication of Highly Ordered Silicon Oxide Dots and Stripes from Block Copolymer Thin Films, Advanced Materials, vol. 20, pp. 681-685, 2008.
Park, Sang-Min, et al., "Directed assembly of lamellae-forming block copolymers using chemically and topographically patterned substrates," Advanced Materials, vol. 19, No. 4, pp. 607-611, Feb. 2007.
PCT International Search Report for Application No. PCT/US2008/060520, dated Sep. 11, 2008, 4 pages.
Reed, M.A., et al., "Molecular random access memory cell," Appl. Phys. Lett., vol. 78, No. 23, pp. 3735-3737, Jun. 2001.
Rozkiewicz, Dorota I., et al., "'Click' Chemistry by Microcontact Printing," Angew. Chem. Int. Ed., vol. 45, pp. 5292-5296, 2006.
Ruiz, R., et al., "Induced Orientational Order in Symmetric Diblock Copolymer Thin-Films," Advanced Materials, vol. 19, No. 4, pp. 587-591, (2007).
Sato et al., Novel Antireflective Layer Using Polysilane for Deep Ultraviolet Lithography, J. Vac. Sci. Technol. B, vol. 17, No. 6, pp. 3398-3401 (1999).
Sohn et al., Fabrication of the Multilayered Nanostructure of Alternating Polymers and Gold Nanoparticles with Thin Films of Self-Assembling Diblock Copolymers, Chem, Mater, vol. 13, pp. 1752-1757 (2001).
Tadd et al, Spatial Distribution of Cobalt Nanoclusters in Block Copolymers, Langmuir, vol. 18, pp. 2378-2384 (2002). [Published on Web Feb. 8, 2002].
Written Opinion of the International Searching Authority for International Application No. PCT/US2009/062117 dated Jun. 1, 2010, 3 pages.
Xia et al., An Approach to Lithographically Defined Self-Assembled Nanoparticle Films, Advanced Materials, vol. 18, pp. 930-933 (2006).
Xia, Younan, et al., "Soft Lithography," Annu. Rev. Mater. Sci., vol. 28, pp. 153-184, 1998.
Chai et al., Assembly of Aligned Linear Metallic Patterns on Silicon, Nature Nanotechnology, vol. 2, Aug. 2007, pp. 500-506.
Chai et al., Using Cylindrical Domains of Block Copolymers to Self-Assemble and Align Metallic Nanowires, ACS Nano, Mar. 2008, vol. 2, No. 3, pp. 489-501.
Fujita et al., Thin Silica Film with a Network Structure as Prepared by Surface Sol-Gel Transcription on the Poly (styrene-b-4-vinylpyridine) Polymer Film, Chemistry Letters, vol. 32, No. 4, Dec. 31, 2003, pp. 352-353.
Melde et al., Silica Nanostructures Templated by Oriented Block Copolymer Thin Films Using Pore-Filling and Selective-Mineralization Routes, Chem. Mater., vol. 17, No. 18, Aug. 13, 2005, pp. 4743-4749.

* cited by examiner

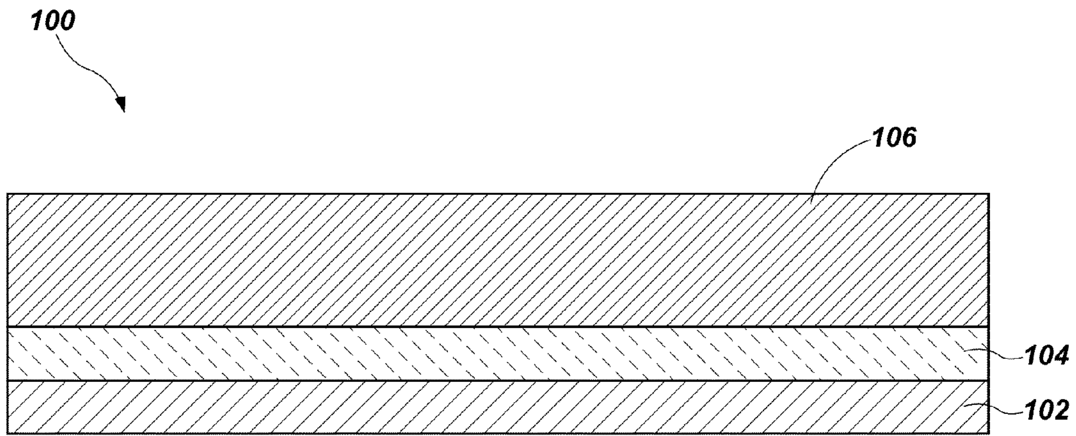


FIG. 1A

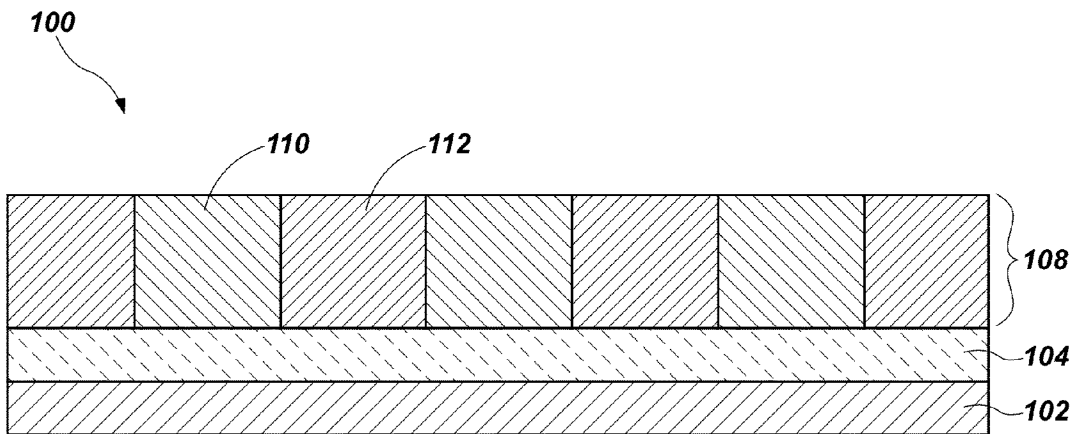


FIG. 1B

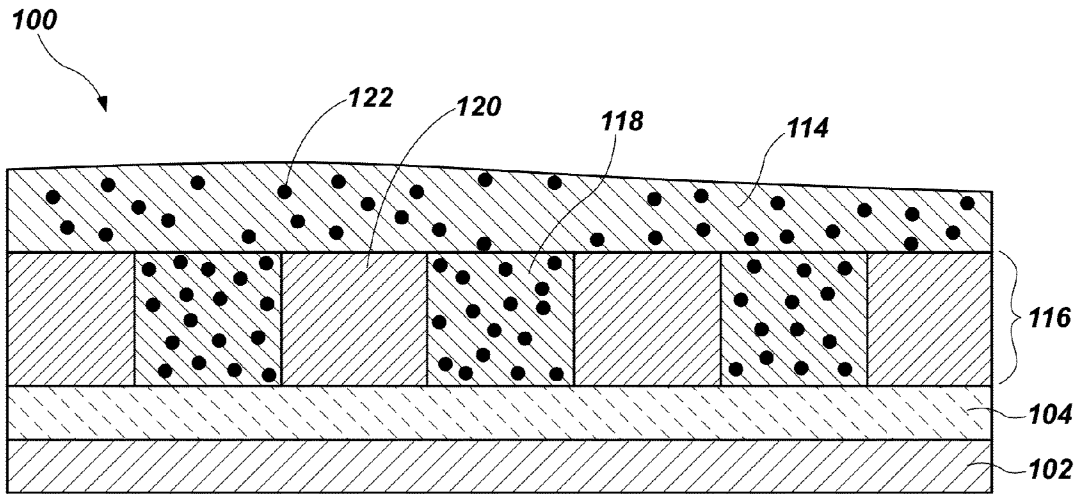


FIG. 1C

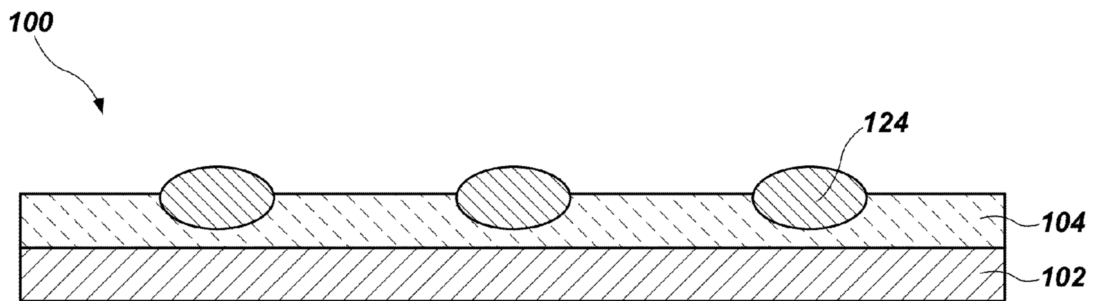


FIG. 1D

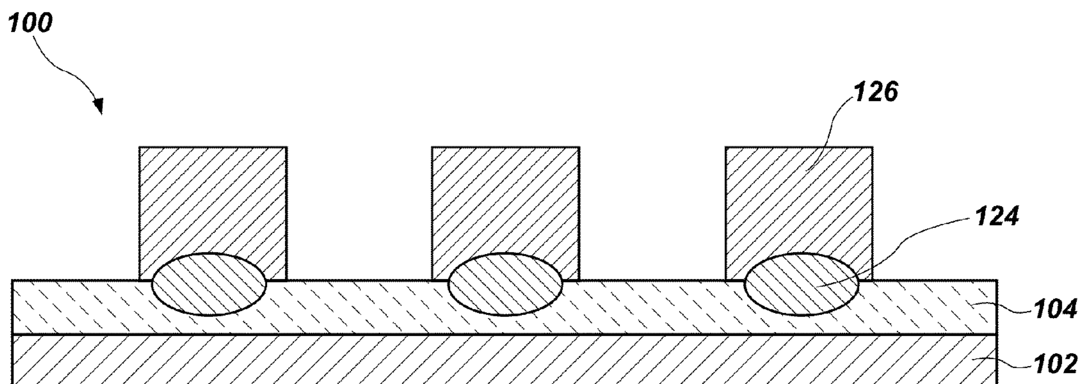


FIG. 1E

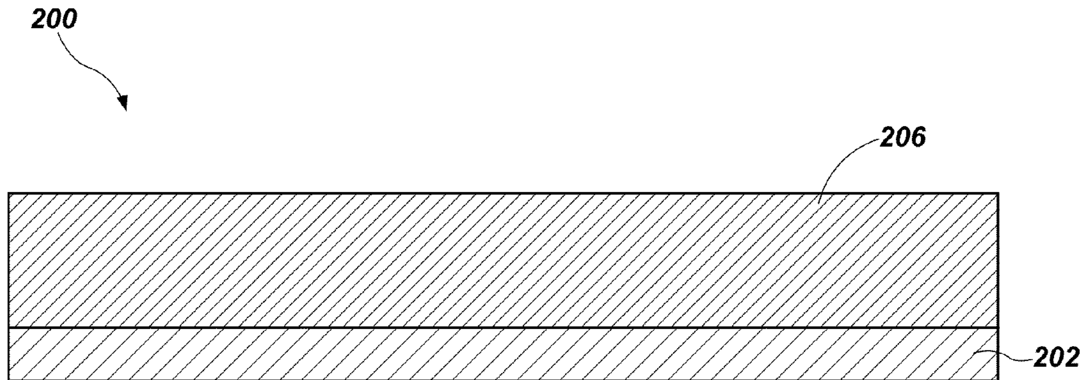


FIG. 2A

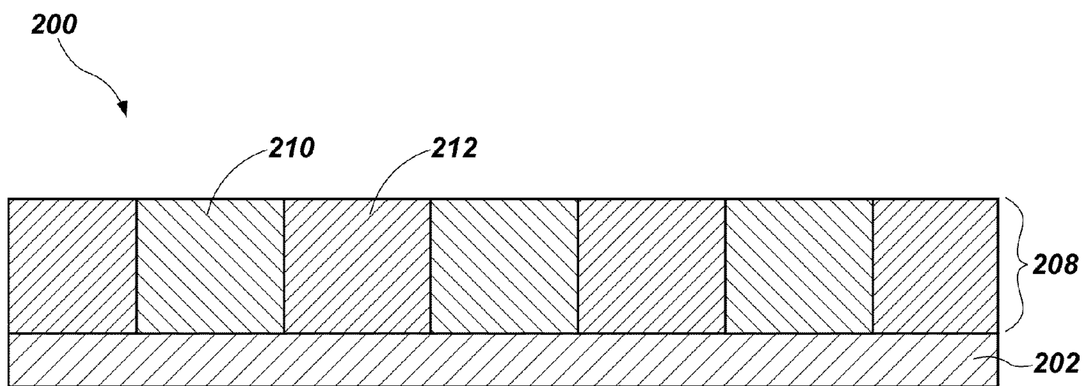


FIG. 2B

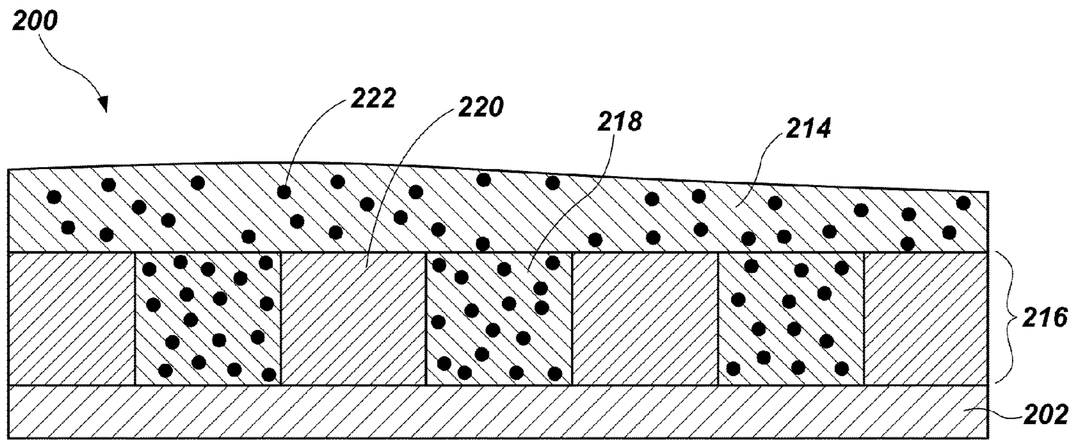


FIG. 2C

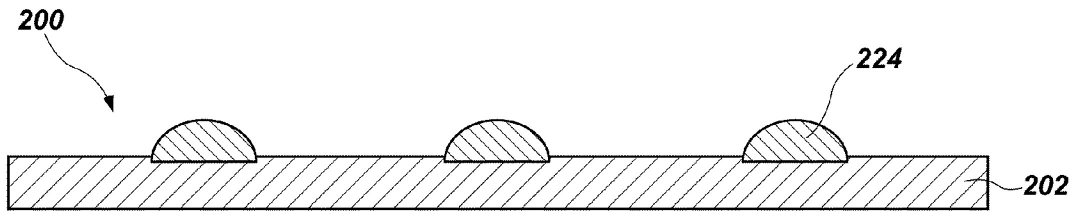


FIG. 2D

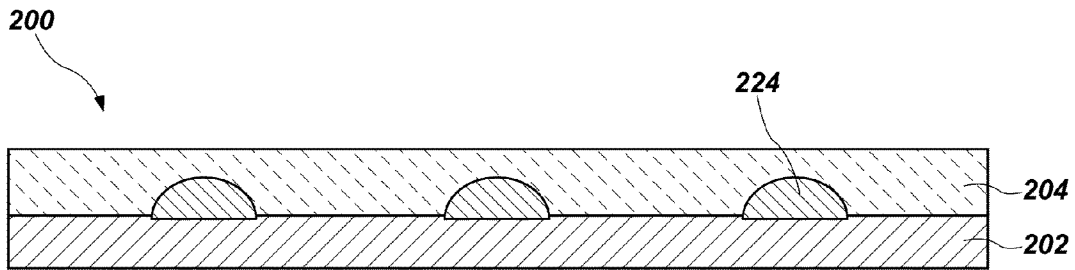


FIG. 2E

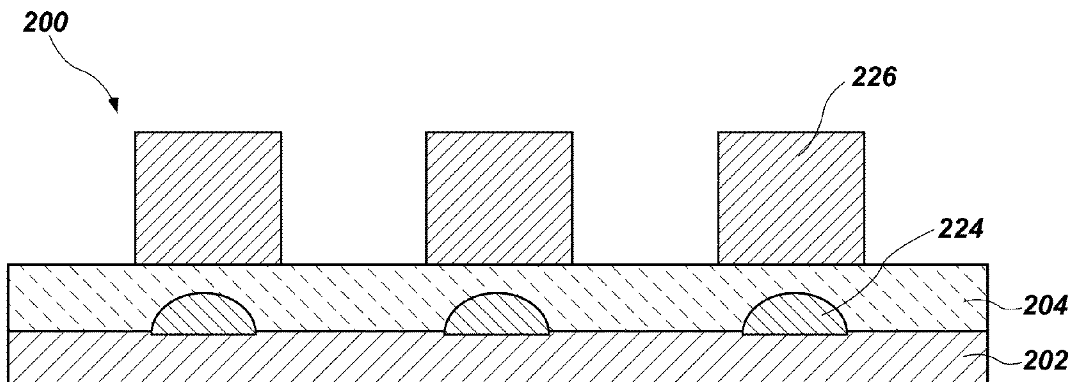


FIG. 2F

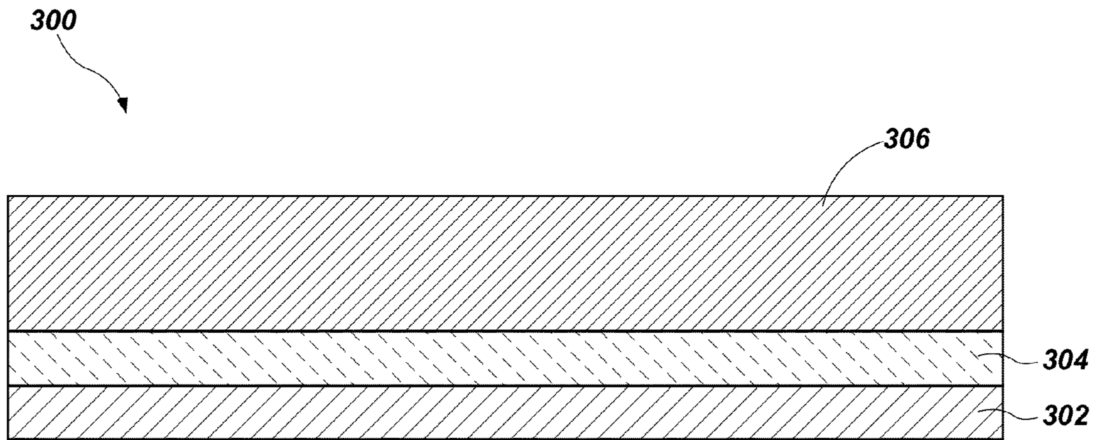


FIG. 3A

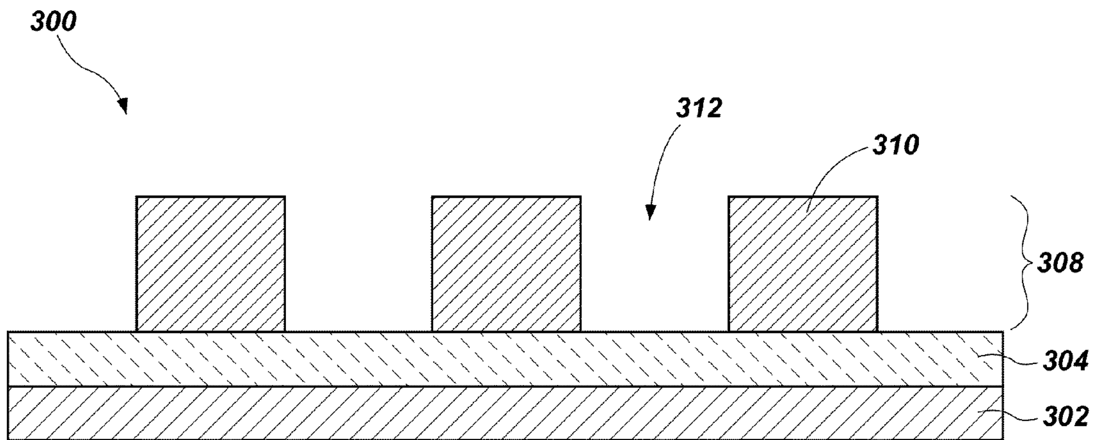


FIG. 3B

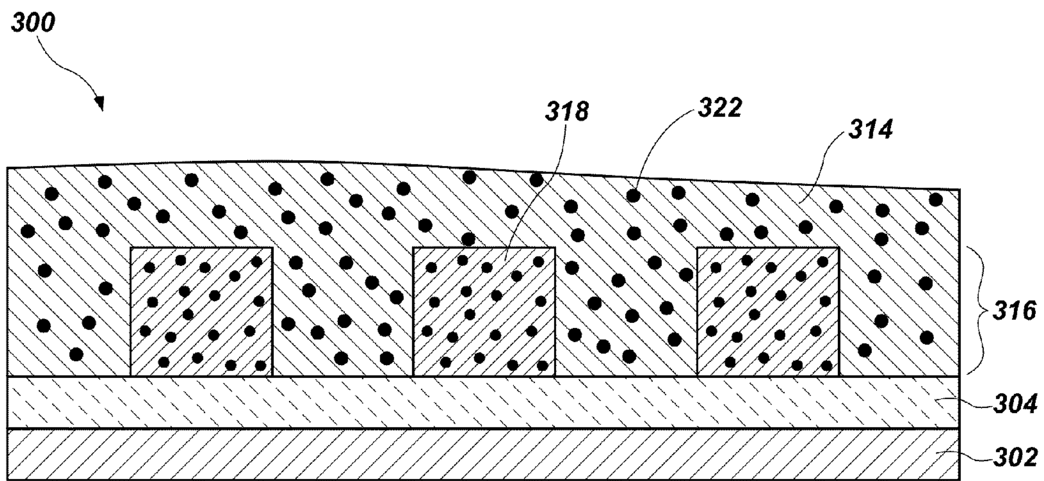


FIG. 3C

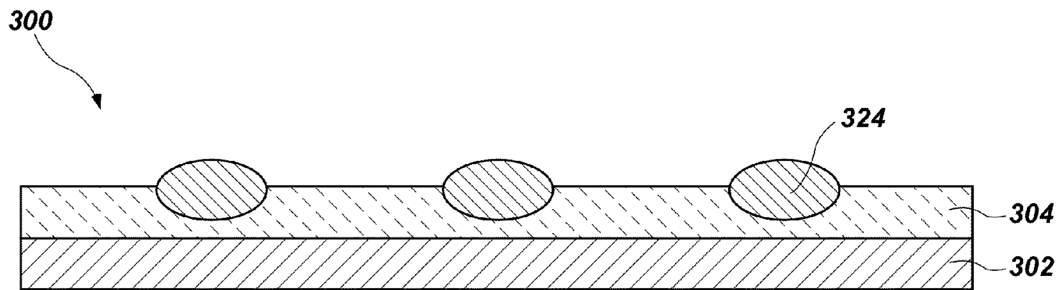


FIG. 3D

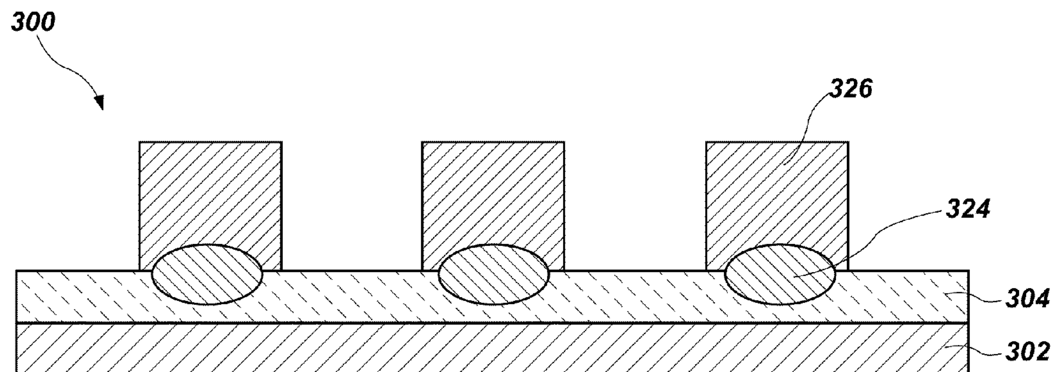


FIG. 3E

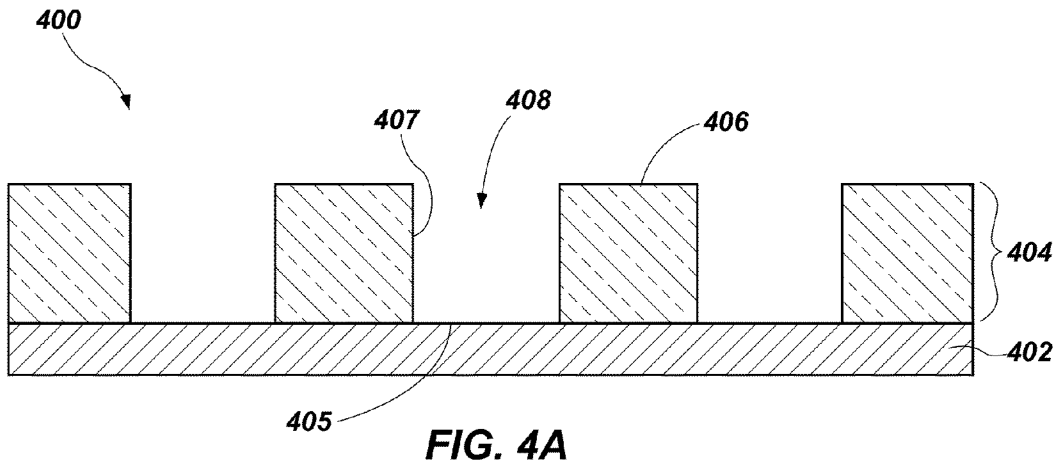


FIG. 4A

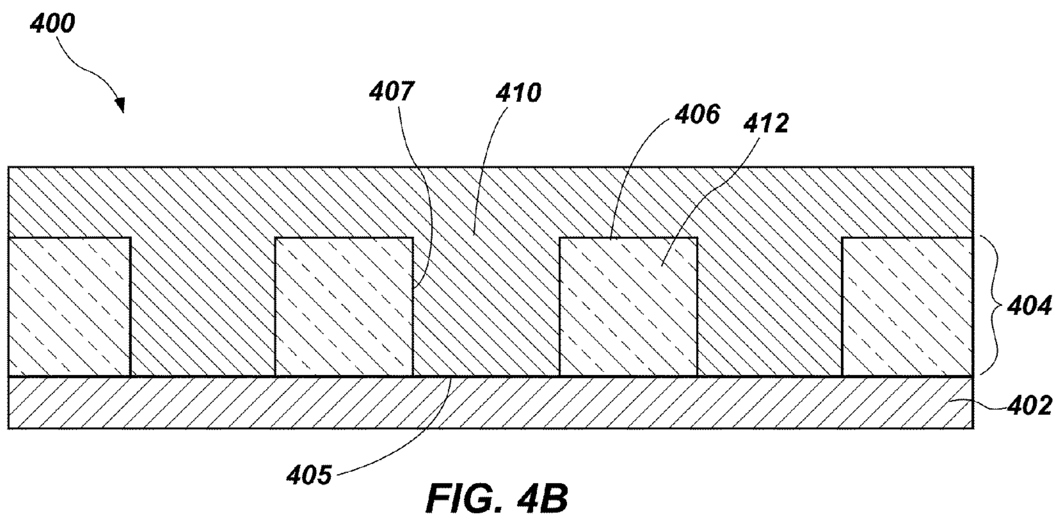


FIG. 4B

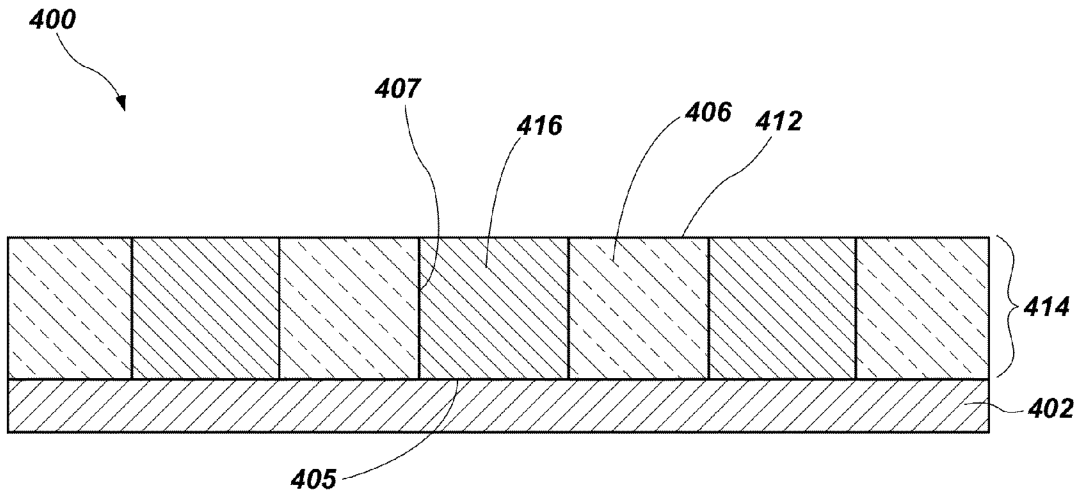


FIG. 4C

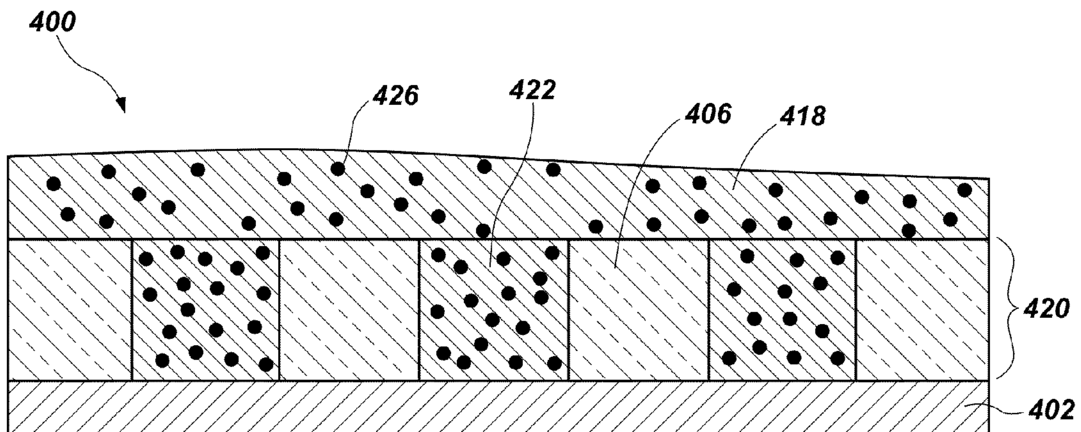


FIG. 4D

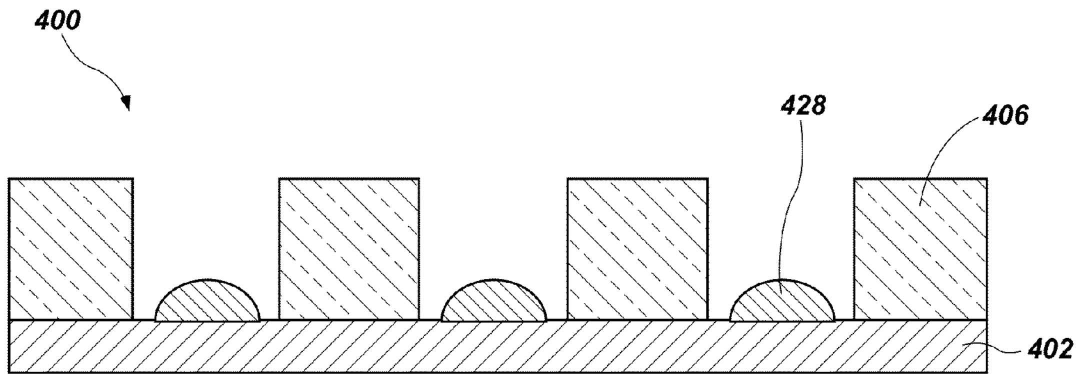


FIG. 4E

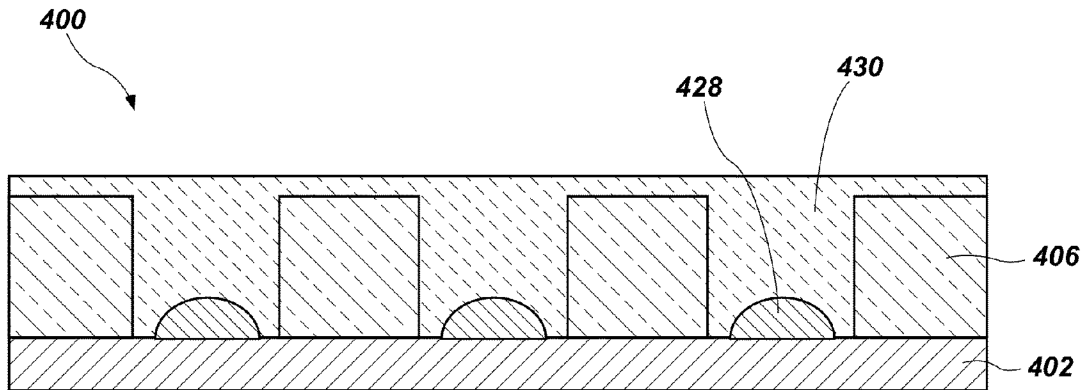


FIG. 4F

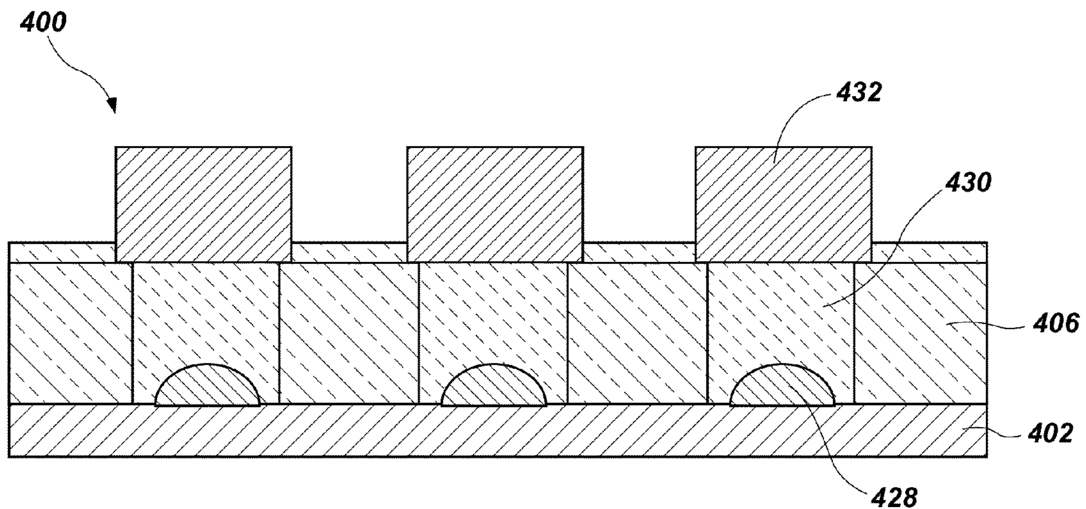


FIG. 4G

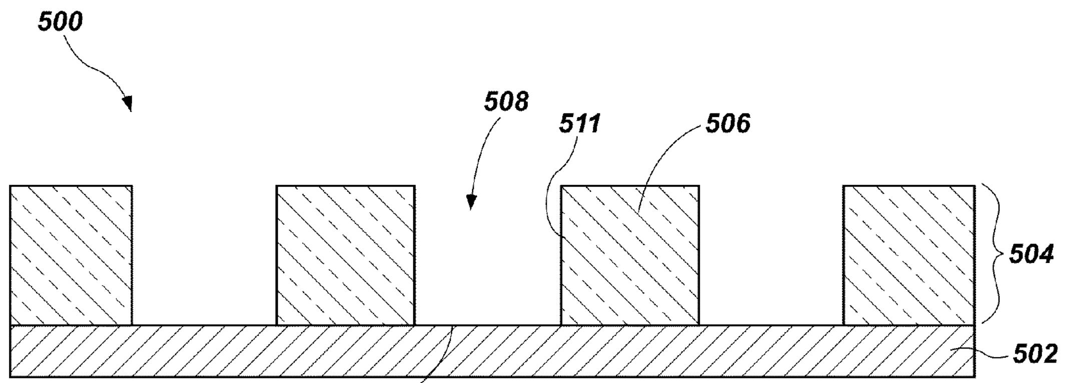


FIG. 5A

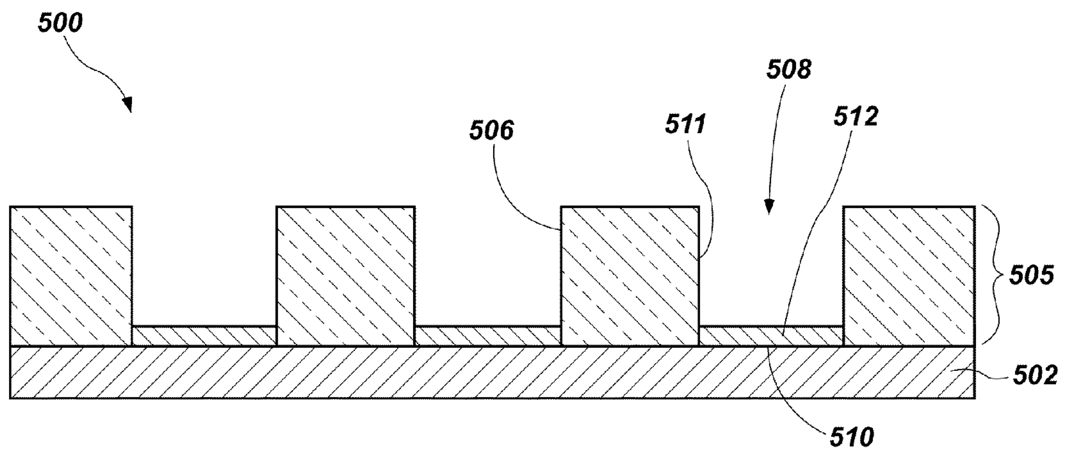


FIG. 5B

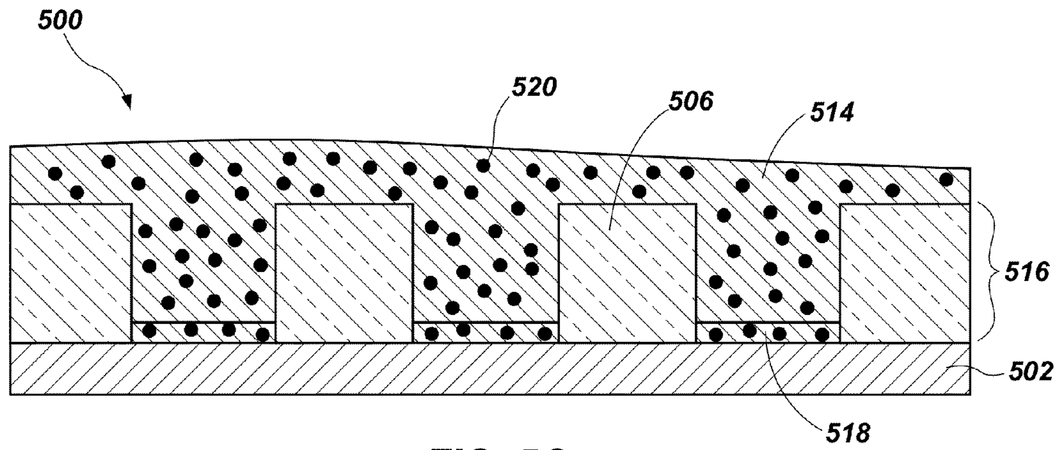


FIG. 5C

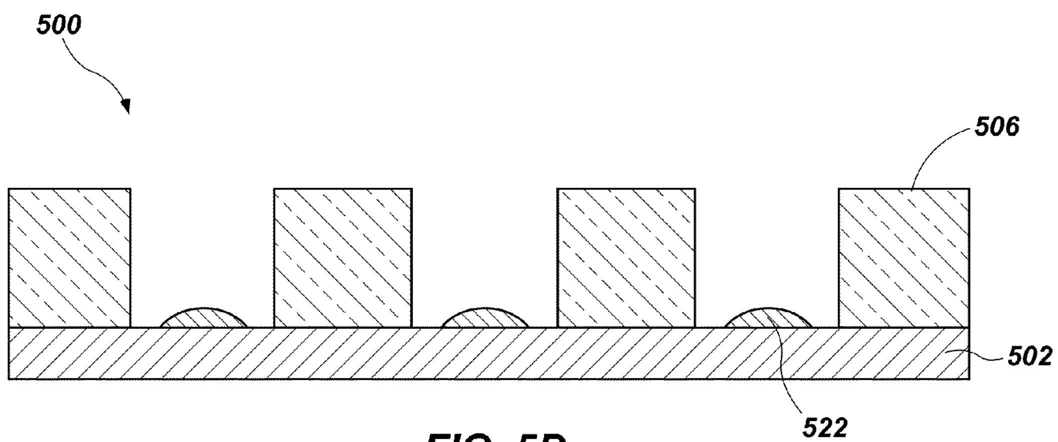


FIG. 5D

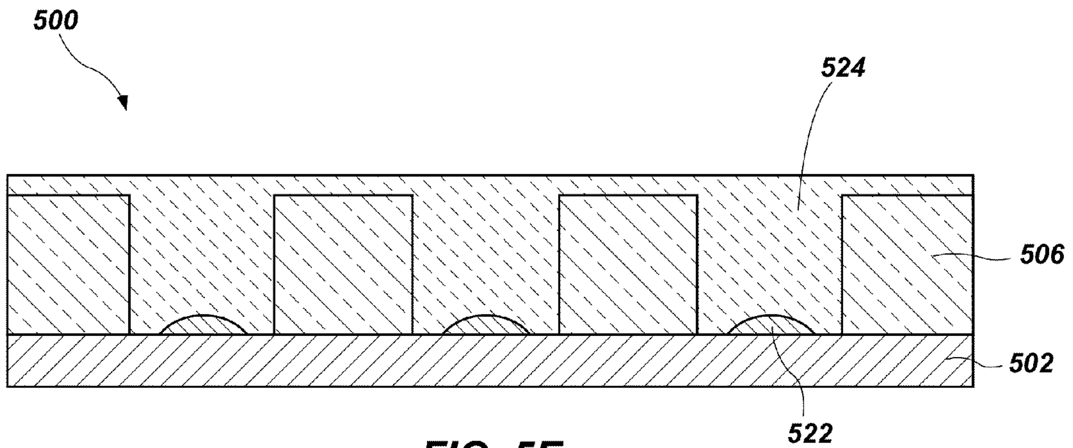


FIG. 5E

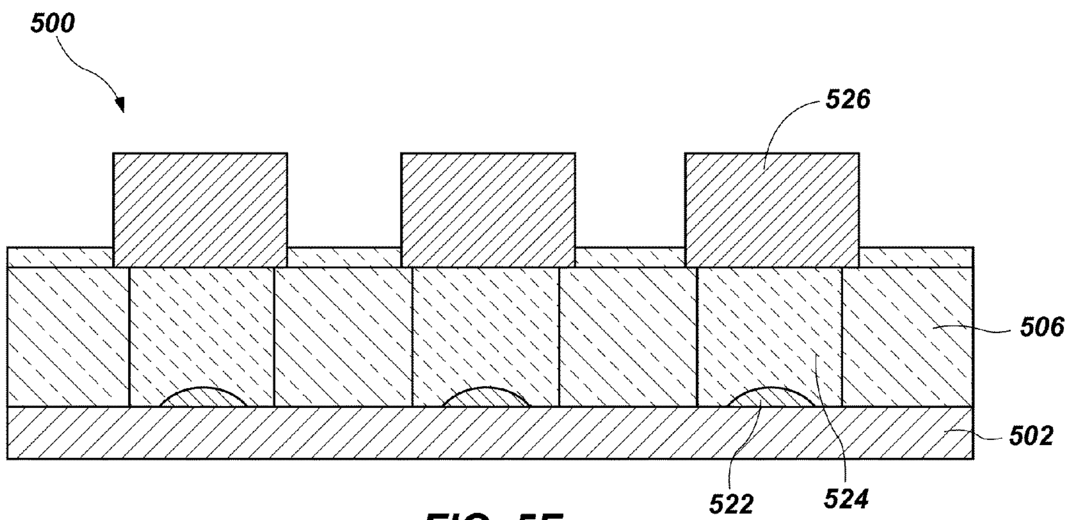


FIG. 5F

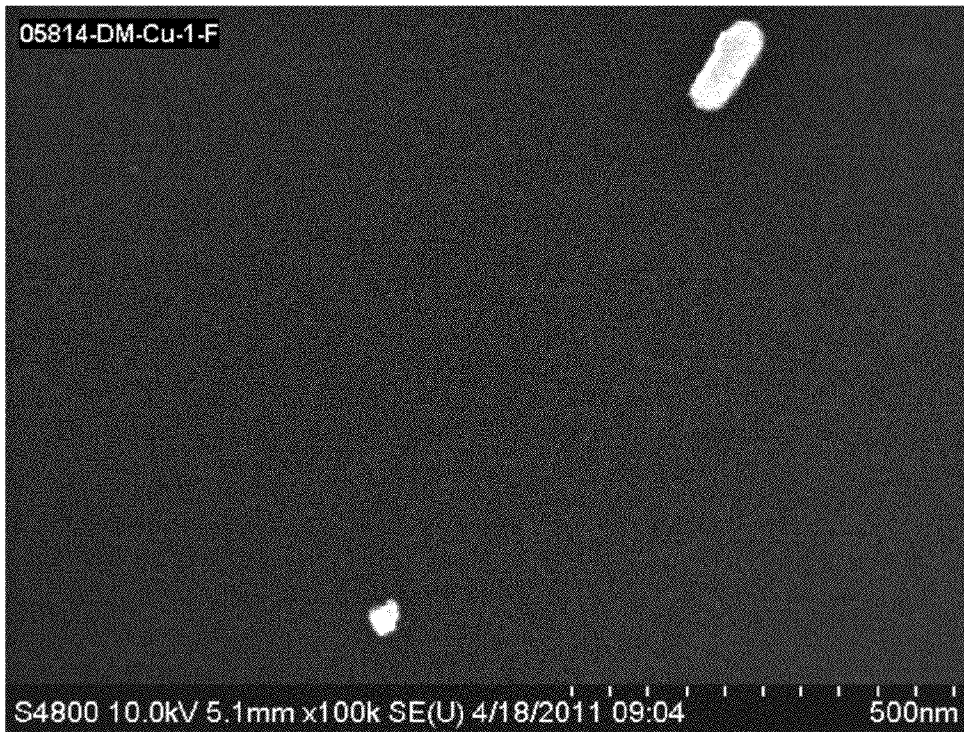


FIG. 6A

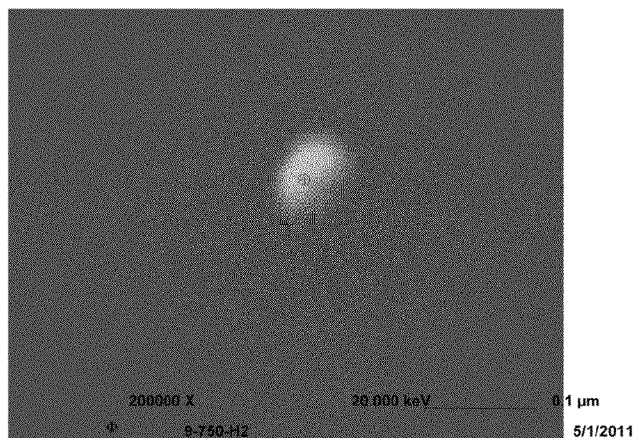


FIG. 6B

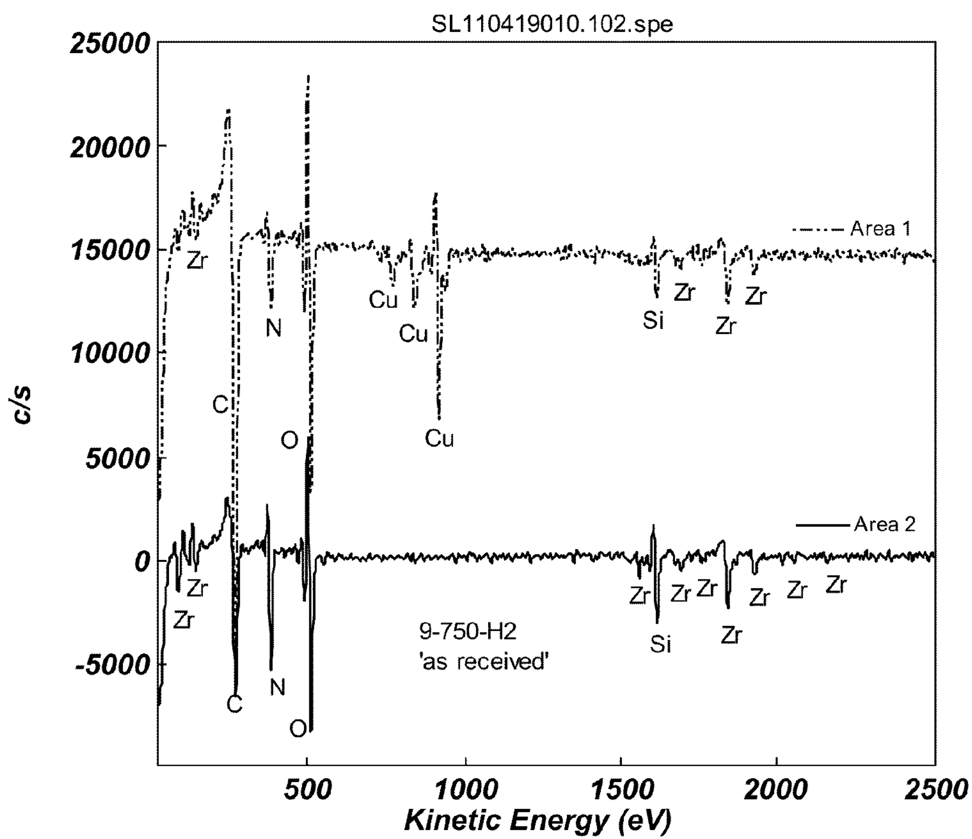


FIG. 7A

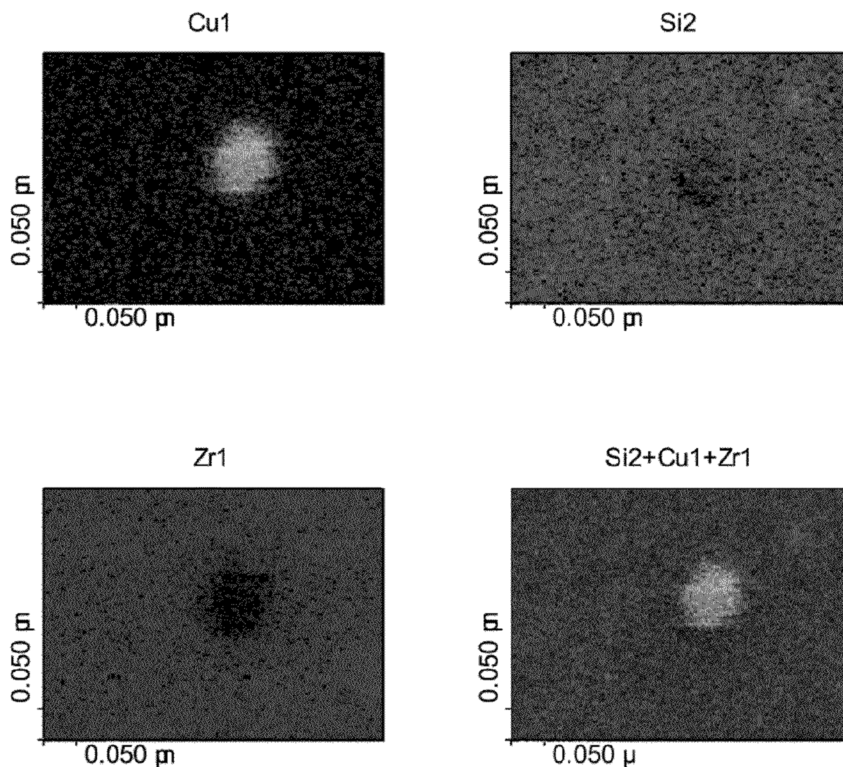


FIG. 7B

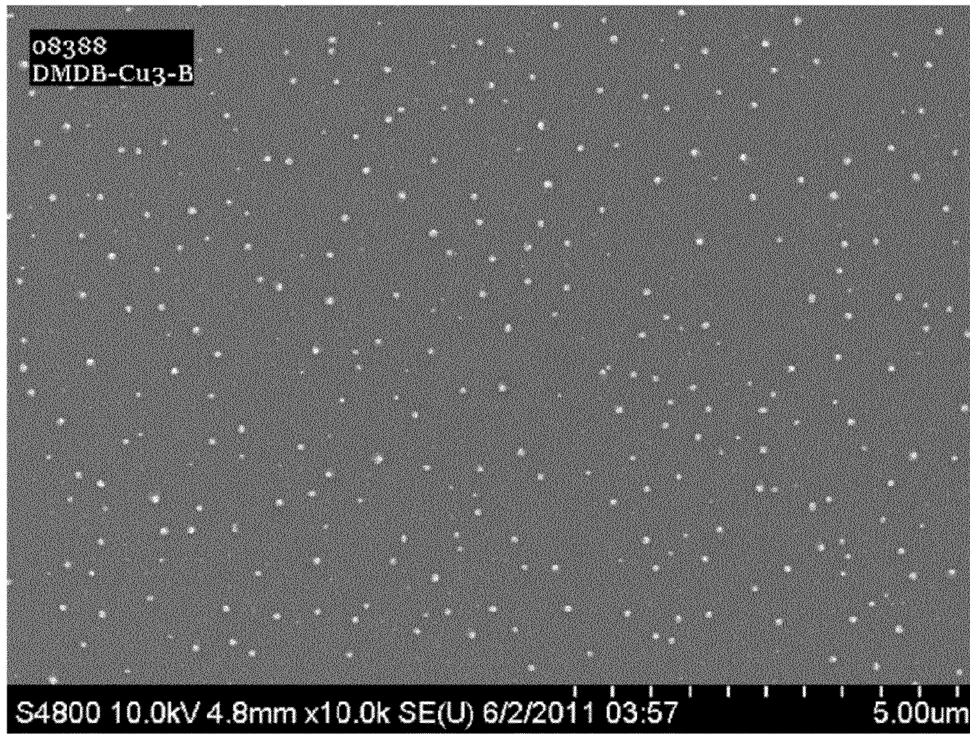


FIG. 8A

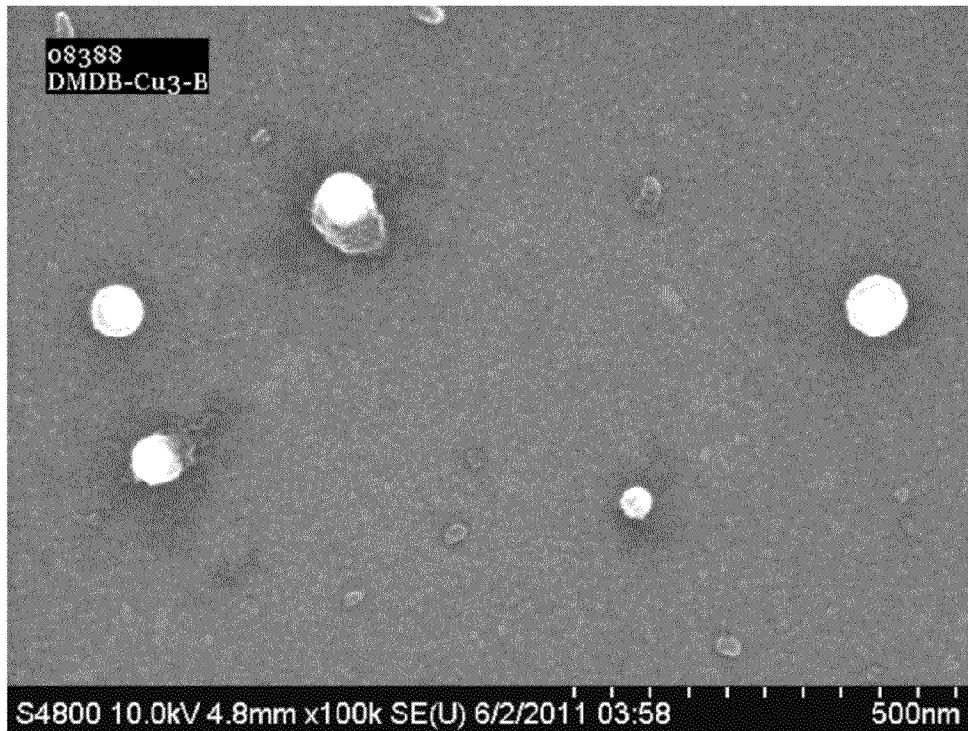


FIG. 8B

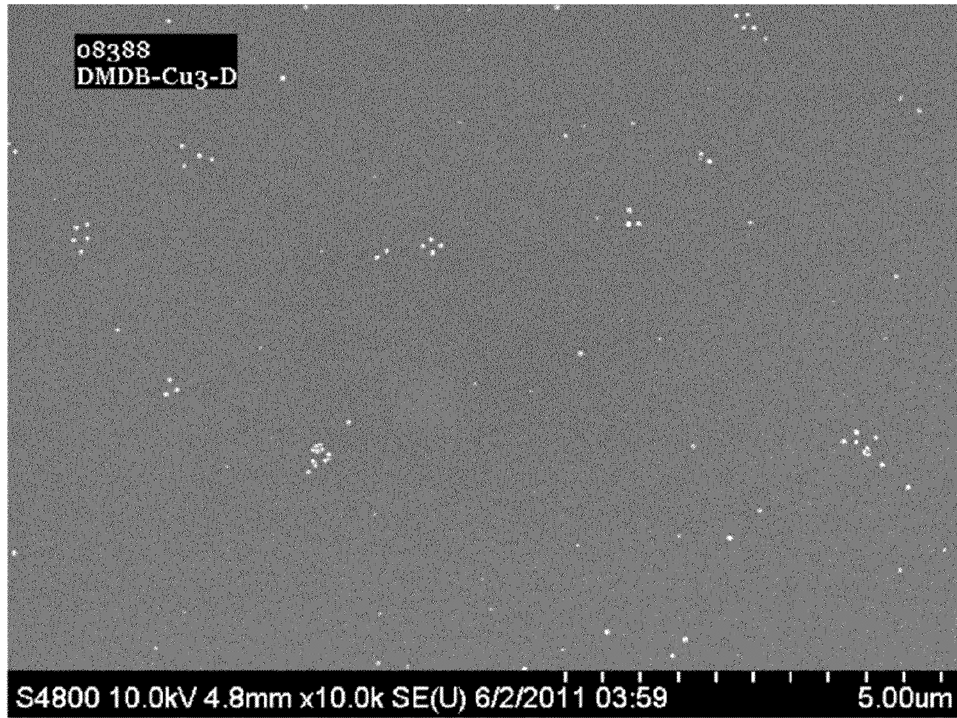


FIG. 9A

FIG. 9B

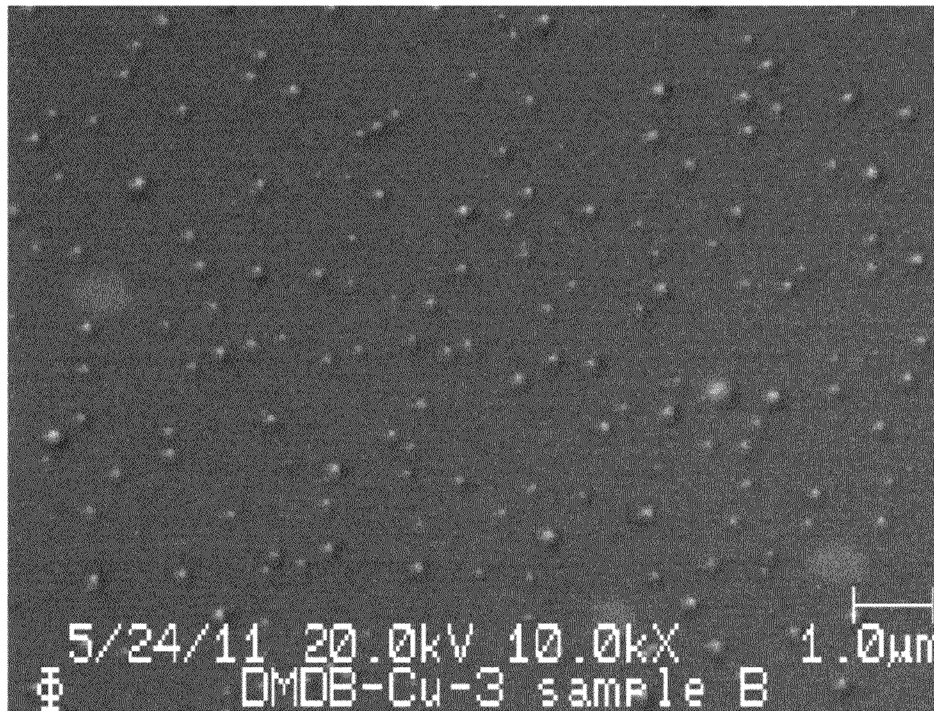


FIG. 10A

FIG. 10B

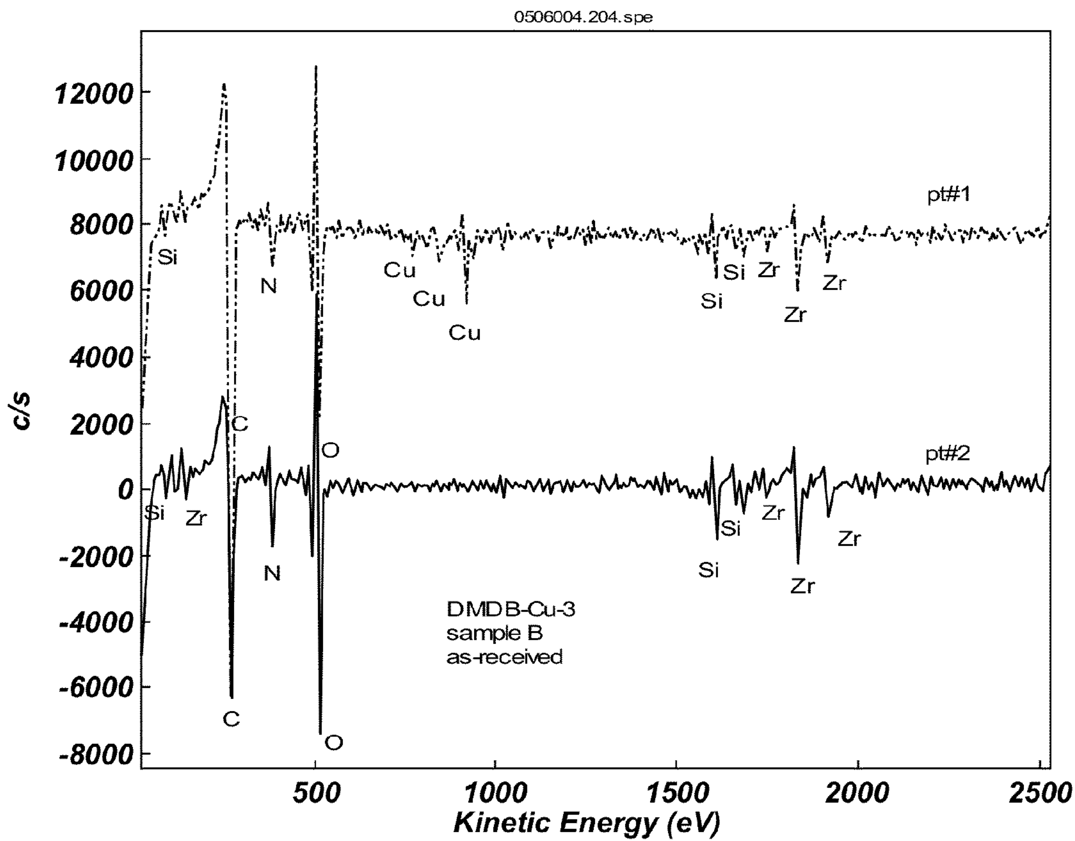


FIG. 11A

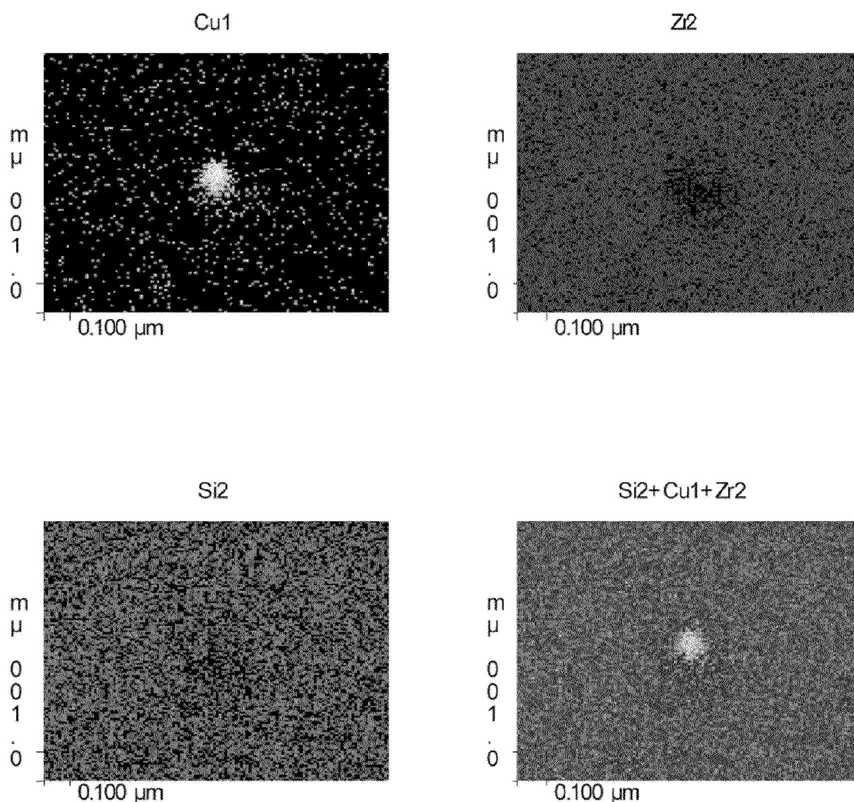


FIG. 11B

METHODS OF FORMING SEMICONDUCTOR DEVICE STRUCTURES, AND RELATED STRUCTURES

TECHNICAL FIELD

Embodiments of the present disclosure relate to methods of forming metal structures for semiconductor device structures, to related methods of forming memory cells, and to related semiconductor device structures.

BACKGROUND

Integrated circuits (ICs), the key components in thousands of electronic systems, generally include interconnected networks of electrical components fabricated on a common foundation, or substrate. Metal structures are commonly used to electrically connect semiconductor features, such as capacitors or transistors, or to define a specific IC, such as a computer memory or microprocessor. The deposition and processing methods used to form the metal structures may affect the quality of the metal structures and impact overall manufacturability, performance, and lifetime of the IC. Thus, the methods used to form the metal structures are increasingly determining the limits in performance, density and reliability of integrated circuits.

As a non-limiting example, the deposition and processing methods used to form active electrodes for memory cells of conductive bridging random access memory (CBRAM) devices may greatly affect the performance and reliability of such devices. Memory cells of CBRAM devices conventionally utilize metallic or ionic forms of silver (Ag) or copper (Cu) to form a conductive bridge between an inert electrode and an active electrode. The active electrode serves as the source of the Ag or Cu. The conductive bridge is formed by the drift (e.g., diffusion) of Ag or Cu cations (by application of a voltage across the electrodes) from the active electrode, through an active material of the memory cell, and to the inert electrode, where the Ag or Cu ions are electro-chemically reduced. The conductive bridge may be removed (by applying a voltage with reversed polarity across the electrodes) or may remain in place indefinitely without needing to be electrically refreshed or rewritten.

A problem with the fabrication of CBRAM devices arises due to the difficulty of processing the Ag or Cu. For example, Cu cannot be etched with conventional RIE techniques, and is typically processed in a damascene flow. Also, there are currently no chemical vapor deposition (CVD) or atomic layer deposition (ALD) techniques for Ag. In addition, the ability to deposit Cu and Ag in small openings is limited. Therefore, deposition is conventionally conducted by physical vapor deposition (PVD), which limits the scalability of Ag damascene flows. It is, therefore, currently of interest to minimize the extent of Ag or Cu processing during the integration and fabrication of semiconductor devices, such as CBRAM devices.

Selective deposition techniques are one way of minimizing Ag or Cu processing. In such techniques, pre-patterned chemical specificity enables materials, such as Ag or Cu, to be preferentially deposited only in desired locations, which avoid the need to etch or polish such materials. Electroless plating is a conventional selective deposition technique. However, electroless plating exhibits variability in nucleation and growth rates, which may disadvantageously result in inconsistencies in the volume of metal deposited at each site within a memory array, significantly impacting operations where the quantity of selectively deposited metal must be

critically controlled. Electroless plating also requires substrates that are electrochemically active, whereas, in certain semiconductor devices (e.g., MOS devices, MIM devices, and CBRAM devices), it is desirable to selectively deposit materials to substrates that are electrochemically inactive (e.g., dielectric materials). Accordingly, improved methods of forming metal structures for semiconductor devices (e.g., CBRAM devices) using selective deposition techniques are desired, as are related methods of forming memory cells.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIGS. **1**A through **1**E are partial cross-sectional views of a semiconductor structure and illustrate a method of forming a metal structure for a semiconductor device structure in accordance with embodiments of the present disclosure;

FIGS. **2**A-**2**F are partial cross-sectional views of a semiconductor structure and illustrate another method of forming a metal structure for a semiconductor device structure in accordance with embodiments of the present disclosure;

FIGS. **3**A-**3**E are partial cross-sectional views of a semiconductor device structure and illustrate yet another method of forming a metal structure for a semiconductor device structure in accordance with embodiments of the present disclosure;

FIGS. **4**A-**4**G are partial cross-sectional views of a semiconductor device structure and illustrate yet still another method of forming a metal structure for a semiconductor device structure in accordance with embodiments of the present disclosure;

FIGS. **5**A-**5**F are partial cross-sectional views of a semiconductor device structure and illustrate yet still an additional method of forming a metal structure for a semiconductor device structure in accordance with embodiments of the present disclosure;

FIG. **6**A is a scanning electron micrograph image showing a top-down view of copper particles formed on a semiconductor device structure, as described in Example 1;

FIG. **6**B is a magnified scanning electron micrograph image showing a top-down view of a single copper particle formed on a semiconductor device structure, as described in Example 1;

FIG. **7**A is a graph of Auger analysis of the single copper particle shown in FIG. **6**B, as described in Example 1;

FIG. **7**B is an Auger electron map of the single copper particle shown in FIG. **6**B, as described in Example 1;

FIG. **8**A is a scanning electron micrograph image showing a top-down view of copper particles formed on a semiconductor device structure, as described in Example 2;

FIG. **8**B is a magnified scanning electron micrograph image showing a top-down view of copper particles formed on a semiconductor device structure, as described in Example 2;

FIG. **9**A is a scanning electron micrograph image showing a top-down view of copper particles formed on a semiconductor device structure, as described in Example 2;

FIG. **9**B is a magnified scanning electron micrograph image showing a top-down view of copper particles formed on a semiconductor structure, as described in Example 2;

FIG. **10**A is a scanning electron micrograph image showing a top-down view of copper particles formed on a semiconductor device structure, as described in Example 2;

FIG. **10**B is a magnified scanning electron micrograph image showing a top-down view of a single copper particle formed on a semiconductor device structure, as described in Example 2;

FIG. **11**A is a graph of Auger analysis of the single copper particle shown in FIG. **10**B, as described in Example 2; and

FIG. **11**B is an Auger electron map of the single copper particle shown in FIG. **10**B, as described in Example 2.

DETAILED DESCRIPTION

Methods of forming metal structures of semiconductor device structures are disclosed, as are related methods of forming memory cells, and related semiconductor device structures. The metal structure is formed from the selective and self-limited deposition of a metal, such as copper (Cu), silver (Ag), or alloys thereof. The metal structure is formed by complexing a metal precursor with a polymer that is configured to react with or couple to the metal precursor and has been applied to predetermined or patterned locations on a semiconductor substrate. The amount of metal precursor complexed with the polymer is limited at least by the amount of metal precursor applied to the polymer and the number of available binding or complexing sites in the polymer. The polymer may be removed and the metal precursor reduced to form the metal structure. By way of example and not limitation, the metal structure may be an electrode or an interconnect. In one embodiment, the metal structure may be used as an active electrode for a memory cell of a conductive bridge random access memory (CBRAM) device. As used herein, the term "active electrode" means and includes a conductive material, such as Cu or Ag, which serves as a source of metal ions (e.g., Cu^+, Ag^+) for formation of the conductive bridge. The metal structure may also be used as a conductive interface in a via, or as a nucleation site (e.g., a seed material) for subsequent metal deposition, such as electroless deposition. The selective and self-limited metal deposition processes disclosed herein may overcome difficulties with conventional processing of metals (e.g., difficulties processing Cu and Ag, such as difficulties etching and/or depositing Cu and Ag into small structures), decrease the deposition variability of current selective deposition technologies (e.g., electroless plating, autocatalytic deposition), and enable increased performance in semiconductor device structures (e.g., memory cells) and semiconductor devices (e.g., CBRAM devices) that rely on specific and uniform quantities of metal.

The following description provides specific details, such as material types, material thicknesses, and processing conditions in order to provide a thorough description of embodiments of the present disclosure. However, a person of ordinary skill in the art will understand that the embodiments of the present disclosure may be practiced without employing these specific details. Indeed, the embodiments of the present disclosure may be practiced in conjunction with conventional fabrication techniques employed in the industry. In addition, the description provided below does not form a complete process flow for manufacturing a semiconductor device. The semiconductor structures described below do not form a complete semiconductor device. Only those process acts and structures necessary to understand the embodiments of the present disclosure are described in detail below. Additional acts to form the complete semiconductor device from the intermediate semiconductor structures may be performed by conventional fabrication techniques. Also note, any drawings accompanying the present application are for illustrative purposes only, and are thus not drawn to scale. Additionally, elements common between figures may retain the same numerical designation.

As used herein, relational terms, such as "first," "second," "over," "top," "bottom," "underlying," etc., are used for clarity and convenience in understanding the disclosure and accompanying drawings and does not connote or depend on any specific preference, orientation, or order, except where the context clearly indicates otherwise.

FIGS. **1**A through **1**E, are simplified partial cross-sectional views illustrating embodiments of a method of forming at least one metal structure for a semiconductor device structure, such as an active electrode of a memory cell (e.g., for a CBRAM device), a conductive interface in a via, or a nucleation site. Referring to FIG. **1**A, semiconductor device structure **100** may include an electrode **102**, an active material **104**, and a block copolymer material **106**. The active material **104** may be formed over and in contact with the first electrode **102**, and the block copolymer material **106** may be formed over and in contact with the active material **104**.

The electrode **102** may include any suitable conductive material including, but not limited to, a metal, a metal alloy, a conductive metal oxide, or combinations thereof. For example, the first electrode **102** may be formed from tungsten (W), tungsten nitride (WN), nickel (Ni), tantalum nitride (TaN), platinum (Pt), gold (Au), titanium nitride (TiN), titanium silicon nitride (TiSiN), titanium aluminum nitride (TiAlN), molybdenum nitride (MoN), or a combination thereof. In at least some embodiments, the first electrode **102** is formed from W. The electrode **102** may be formed in, on, or over a substrate (not shown) using conventional techniques, such as chemical vapor deposition (CVD), physical vapor deposition (PVD), or atomic layer deposition (ALD). As used herein, the term "substrate" means and includes a base material or construction upon which additional materials are formed. The substrate may be a semiconductor substrate, a base semiconductor layer on a supporting structure, a metal electrode or a semiconductor substrate having one or more layers, structures or regions fondled thereon. The substrate may be a conventional silicon substrate or other bulk substrate comprising a layer of semiconductive material. As used herein, the term "bulk substrate" means and includes not only silicon wafers, but also silicon-on-insulator (SOI) substrates, such as silicon-on-sapphire (SOS) substrates and silicon-on-glass (SOG) substrates, epitaxial layers of silicon on a base semiconductor foundation, and other semiconductor or optoelectronic materials, such as silicon-germanium, germanium, gallium arsenide, gallium nitride, and indium phosphide. The substrate may be doped or undoped.

The active material **104** may be a solid state electrolyte material, such as at least one of a chalcogenide compound, a transition metal oxide, and a silicon oxide. As used herein, the term "chalcogenide compound" refers to a binary or multinary compound that includes at least one chalcogen and a more electropositive element or radical. As used herein, the term "chalcogen" refers to an element of Group VI of the Periodic Table, such as oxygen (O), sulfur (S), selenium (Se), or tellurium (Te). The electropositive element may include, but is not limited to, nitrogen (N), silicon (Si), nickel (Ni), gallium (Ga), germanium (Ge), arsenic (As), silver (Ag), indium (In), tin (Sn), antimony (Sb), gold (Au), lead (Pb), bismuth (Bi), or combinations thereof. The chalcogenide compound may be a binary, ternary, or quaternary alloy. As used herein, the term "transition metal oxide" means and includes an oxide of an element of Groups VB, VIB, VIIB, VIII, IB, and IIB of the Periodic Table, such as copper oxide (CuO), cobalt oxide (CoO), iron oxide (Fe_2O_3), nickel oxide (NiO), magnesium oxide (MnO_2), zinc oxide (ZnO), and titanium oxide (TiO_2). The silicon oxide may, for example, be silicon dioxide (SiO_2). In at least some embodiments, the active material **104** is SiO_2. The active material **104** may be formed over and in contact with the electrode **102** using conventional techniques, such as CVD, PVD, or ALD.

As used herein, the term "block copolymer material" means and includes a polymer material including two or more polymer blocks covalently bound to one or more polymer blocks of unlike type. The block copolymer material **106** may be selected based on an ability of at least one polymer block to form a complex with a metal precursor, as described in further detail below. At least one of the polymer blocks may include at least one functional group that is configured to interact with the metal precursor to form the complex. The block copolymer material **106** may be a diblock copolymer material (i.e., copolymer material including two polymer blocks), a triblock copolymer (i.e., a copolymer material including three polymer blocks), or a multiblock copolymer (i.e., a copolymer material including more than three polymer blocks). The different polymer blocks of the block copolymer material may be substantially immiscible in one another. By way of non-limiting example, the block copolymer material **106** may be a diblock copolymer including a hydrophobic block and a hydrophilic block. The hydrophobic block may include a polymer substantially insoluble in a solvent (e.g., an inert polar solvent, such as at least one of water and an organic solvent, such as an alcohol, tetrahydrofuran, and diemthylformamide). The hydrophilic block may include a polymer that swells upon contact with the solvent. In at least some embodiments, the block copolymer material is polystryene-block-poly-2-vinylpryidine (PS-2-P2VP). A ratio of the hydrophilic block to the hydrophobic block may be within a range of from about 80:20 by weight to about 50:50 by weight and, such as about 70:30 by weight. The block copolymer material **106** may be applied over and in contact with the active material **104** by conventional techniques, such as spin casting, spin coating, spraying, ink coating, or dip coating.

Referring to FIG. **1**B, an annealing process may be used to initiate phase separation between polymer blocks of the block copolymer material **106** (FIG. **1**A) to form a block copolymer assembly **108** including at least two different domains. The block copolymer assembly **108** may be formed from the block copolymer material **106** (FIG. **1**A) by conventional self-assembly techniques, which are not described in detail herein. The at least two different domains may include at least one first domain **110** (e.g., at least one minority domain) and at least one second domain **112** (e.g., at least one majority domain). One or more of the at least one first domain **110** and the at least one second domain **112** may include features (e.g., cylinders, or lamellae) that extend linearly along a direction normal to a planar surface (e.g., top surface) of at least one of the electrode **102** and the active material **104**. When the block copolymer material **106** (FIG. **1**A) is a diblock copolymer including a hydrophobic block and a hydrophilic block, the at least one first domain **110** may correspond to the hydrophilic block and the at least one second domain **112** may correspond to the hydrophobic block. The annealing process may, for example, include at least one of thermal annealing (e.g., at a temperature greater than the glass transition temperature of the block copolymer material **106** and less than the degradation temperature of the block copolymer material **106**), solvent vapor-assisted annealing (e.g., at a temperature greater than or equal to room temperature), and supercritical fluid-assisted annealing. By way of non-limiting example, the block copolymer material **106** may be thermally annealed by exposing the block copolymer material **106** to a temperature within a range of from about 130° C. to about 275° C. in a vacuum or an inert atmosphere (e.g., a nitrogen atmosphere, an argon atmosphere, or combinations thereof).

Referring to FIG. **1**C, the block copolymer assembly **108** (FIG. **1**B) may be exposed to a staining agent **114** to form a metal-complexed block copolymer assembly **116** including at least one metal-complexed domain **118** and at least one non-metal-complexed domain **120**. As depicted in FIG. **1**C, the at least one first domain **110** (FIG. **1**B) may become the at least one metal-complexed domain **118** and the at least one second domain **112** (FIG. **1**B) may become the at least one non-metal-complexed domain **120**. In additional embodiments, the at least one first domain **110** (FIG. **1**B) may become the at least one non-metal-complexed domain **120** and the at least one second domain **112** (FIG. **1**B) may become the at least one metal-complexed domain **118**.

The staining agent **114** may include at least one metal precursor **122**. The at least one metal precursor **122** may be an elemental metal, an elemental metalloid, or a metal-containing compound capable of selectively coupling with the polymer of one or more domain(s) (e.g., the at least one first domain **110** (FIG. **1**B)) of the at least two different domains relative to the polymer of one or more other domain(s) (e.g., the at least one second domain **112** (FIG. **1**B)) of the at least two different domains. Suitable elemental metals may, for example, include copper, silver, ruthenium, cobalt, nickel, titanium, tungsten, tantalum, molybdenum, platinum, palladium, iridium, gold, and iron. Suitable elemental metalloids may, for example, include silicon, and germanium. Suitable metal-containing compounds may, for example, include metal oxides (e.g., metal alkoxide), and metal salts (e.g., metal halides, metal sulfates, metal cyanides, metal nitrides, and metal nitrates). Optionally, the staining agent **114** may also include at least one solvent. The at least one solvent may be a liquid, gas, or vapor capable of selectively permeating and swelling the one or more domain(s) (e.g., the at least one minority domain **110** (FIG. **1**B)) of the at least two different domains relative to the one or more other domain(s) (e.g., the at least one majority domain **112** (FIG. **1**B)) of the at least two different domains. In at least some embodiments, the staining agent **114** is a mixture of the metal precursor **122** and at least one solvent.

Exposing the block copolymer assembly **108** (FIG. **1**B) to the staining agent **114** may form the metal-complexed block copolymer assembly **116** through at least one of chelation, other ligand interactions, and coulombic interactions. As a non-limiting example, at least where the metal precursor **122** is an elemental metal or an elemental metalloid and the polymer of one or more domain(s) (e.g., the at least one first domain **110** (FIG. **1**B)) includes at least one of unsaturated organic groups (i.e., organic groups having π-orbital electrons) and one or more element(s) of Groups VA and VIA of the Periodic table of Elements (e.g., nitrogen, phosphorus, sulfur, and oxygen) in appropriate spacings and orientations, the polymer of the one or more domain(s) may coordinate with the elemental metal or the elemental metalloid (e.g., charge-neutral forms, and charge-positive forms) through chelation and/or other ligand interactions. As an additional non-limiting example, at least where the metal precursor **122** is a metal-containing compound, the metal precursor **122** may be selectively coupled to the polymer of one or more domain(s) (e.g., the at least one minority domain **110** (FIG. **1**B)) through coulombic interactions by providing a charge to the polymer of the one or more domain(s) opposing a charge provided to the metal-containing compound. For instance, if the polymer of one or more domain(s) (e.g., the at least one minority domain **110** (FIG. **1**B)) includes cationic functionality (e.g., functional groups or constituents that are or may become positively charged, such as pyridine), the staining agent **114** may be an aqueous acid solution including a metal-containing compound including anionic functionality (e.g., functional groups or constituents of the metal-containing compound that are or may become negatively charged). Con-

versely, if the polymer of one or more domain(s) (e.g., the at least one minority domain **110** (FIG. **1**B)) includes anionic functionality (e.g., functional groups or constituents that are or may become negatively charged, such as carboxylic acid groups or thiol groups), the staining agent **114** may be an aqueous base solution including a metal-containing compound including cationic functionality (e.g., functional groups or constituents of the metal-containing compound that are or may become positively charged).

Table 1 below is a non-limiting list of materials and conditions that may be used in combination to form the at least one metal-complexed domain **118** of the metal-complexed block copolymer assembly **116**.

TABLE 1

Exemplary Materials and Conditions for Forming the Metal-Complexed Domain 118

Domain polymer	Complexation pH	Binding Functionality	Metal precursor
Poly(vinylpyridine)	less than 7 (i.e., acidic)	Pyridinium	Ammonium silver (I) thiosulfate
Poly(vinylpyridine)	less than 7 (i.e., acidic)	Pyridinium	Copper (II) chloride
Poly((meth)acrylic acid)	greater than 7 (i.e., basic)	Carboxylic acid	Silver (I) nitrate
Poly((meth)acrylic acid)	greater than 7 (i.e., basic)	Carboxylic acid	Copper (I) chloride

In additional embodiments, the block copolymer assembly **108** (FIG. **1**B) may be exposed to the solvent and the metal precursor **122** described above in a multiple act process. By way of non-limiting example, the block copolymer assembly **108** (FIG. **1**B) may be exposed to the solvent prior to being exposed to the metal precursor **122**. Such a multiple act process may be used to provide the at least one minority domain **110** (FIG. **1**B) with an exposed surface (e.g., where the at least one minority domain **110** is covered by the majority domain **112**), or to at least provide the at least one minority domain **110** (FIG. **1**B) with additional surface area for interaction with the metal precursor **122**.

Accordingly, a semiconductor device structure of the present disclosure may include an electrode, and at least one metal-complexed structure (e.g., at least one metal-complexed domain) overlying the electrode and including at least one of an elemental metal, an elemental metalloid, a metal oxide, and a metal salt coupled to a polymer including features that extend linearly along a direction normal to a planar surface of the electrode.

Referring next to FIG. **1**D, the polymer of the at least one non-metal-complexed domain **120** may be volatized and removed from the metal-complexed block copolymer assembly **116** (FIG. **1**C), and the metal precursor **122** (FIG. **1**C) within the at least one metal-complexed domain **118** (FIG. **1**C) may be reduced (i.e., chemically reduced) to form at least one metal structure **124** over and in contact with the active layer **104**. The at least one metal structure **124** may be formed of a plurality of metal particles (not shown). Each metal particle of the plurality of metal particles may be discontinuous or discrete from each other metal particle of the plurality of metal particles. The polymer may, for example, be volatized and removed by performing a thermal anneal in a reducing atmosphere. The thermal anneal may expose the metal-complexed block copolymer assembly **116** (FIG. **1**C) to a temperature greater than or equal to a decomposition temperature of the polymer of each of the at least one metal-complexed domain **118** (FIG. **1**C) and the at least one non-metal-complexed domain **120** (FIG. **1**C). By way of non-limiting example, the metal-complexed block copolymer assembly **116** may be exposed to a temperature with a range of from about 250° C. to about 750° C. in at least one of an ammonia atmosphere and a hydrogen atmosphere. As shown in FIG. **1**D, during the thermal anneal, at least a portion of the metal structure **124** may diffuse into the active layer **104**. Conventional processes (e.g., electroless plating) may, optionally, be used to increase the size of the metal particles (not shown) of the at least one metal structure **124**.

The metal-complexed block copolymer assembly **116** (FIG. **1**C) may, optionally, be exposed to an oxidizing agent (e.g., air, oxygen, nitrogen dioxide, water, nitrous oxide, dinitrogen tetroxide, ozone, or combinations thereof) prior to performing the thermal anneal in the reducing atmosphere described above. Exposure to the oxidizing agent may convert the metal precursor **122** (FIG. **1**C) within the at least one metal-complexed domain **118** (FIG. **1**C) to a metal oxide (not shown), which may then be reduced to metal by the thermal anneal in the reducing atmosphere. By way of non-limiting example, the semiconductor device structure **100** may be exposed to the oxidizing agent (e.g., ozone) in a sealed chamber at a temperature within a range of from about 25° C. to about 200° C., such as from about 75° C. to about 100° C., for a period of time within a range of from about 30 seconds to about 30 hours, such as from about 30 seconds to about 15 hours, or from about 30 seconds to about 1 hour, or from about 10 minutes to about 1 hour. Exposing the metal-complexed block copolymer assembly **116** (FIG. **1**C) to the oxidizing agent prior to performing the thermal anneal in the reducing atmosphere may enable the thermal anneal to be performed at a lower temperature, decreasing aggregation of the metal particles (not shown). In additional embodiments, after exposing the metal-complexed block copolymer assembly **116** (FIG. **1**C) to the oxidizing agent, the thermal anneal in the reducing atmosphere may be omitted, leaving a metal-oxide-complexed block copolymer assembly (not shown) including at least one metal-oxide-complexed domain (not shown) and at least one non-metal-oxide-complexed domain (not shown). Polymer of the metal-oxide-complexed block copolymer assembly may be volatilized and removed (e.g., by way of a thermal anneal) to form at least one metal oxide structure.

Accordingly, a method of forming a memory cell may include forming a block copolymer assembly including at least two different domains over an electrode. The at least one metal precursor may be selectively coupled to the block copolymer assembly to form a metal-complexed block copolymer assembly including at least one metal-complexed domain and at least one non-metal-complexed domain. The metal-complexed block copolymer assembly may be annealed to form at least one metal structure.

Referring to FIG. **1**E, a structure **126**, such as an electrode or a contact, may be formed over and in contact with the at least one metal structure **124**. The structure **126** may, for example, include a suitable conductive material including, but not limited to, a metal, a metal alloy, a conductive metal oxide, or combinations thereof. By way of non-limiting example, the structure **126** may be formed of W, WN, Ni, TaN, Pt, Ru, Co, CoSi, TiN, TiSiN, TiAlN, or MoN. The structure **126** may be formed of substantially the same material as the electrode **102** or may be a different material than the electrode **102**. In at least some embodiments, the structure **126** is formed from W. The structure **126** may be formed over and in contact with the at least one metal structure **124** using conventional deposition (e.g., CVD, ALD, or PVD) and patterning (e.g., masking and etching) techniques.

FIGS. 2A through 2F, are simplified partial cross-sectional views of a semiconductor device structure **200** illustrating embodiments of another method of forming at least one metal structure for a semiconductor device structure, such as an active electrode of a memory cell (e.g., for a CBRAM device), a conductive interface in a via, or a nucleation site. The semiconductor substrate **200** is substantially similar to the semiconductor substrate **100** described above, except that the metal structures are directly formed on an electrode. Referring to FIG. 2A, the semiconductor structure **200** may include an electrode **202**, and a block copolymer material **206**. The block copolymer material **206** may be formed over and in contact with the electrode **202**, which may be formed in, on, or over a substrate (not shown). The electrode **202** and the block copolymer material **206** may be substantially similar to the electrode **102** and the block copolymer material **106** described above, respectively. The electrode **202** and the block copolymer material **206** may be formed in a process substantially similar to that described above to form the electrode **102** and the block copolymer material **106**, respectively.

Referring next to FIG. 2B, an annealing process may be used to initiate phase separation between blocks of the block copolymer material **206** to form a block copolymer assembly **208** including at least one minority domain **210** and at least one majority domain **212**. The annealing process may be substantially similar to that described above with respect to formation of the block copolymer assembly **108**. The block copolymer assembly **208**, the at least one first domain **210**, and at least one second domain **212** may be substantially similar to the block copolymer assembly **108**, the at least one first domain **110**, and at least one second domain **112** described above, respectively. As shown in FIG. 2C, the block copolymer assembly **208** (FIG. 2B) may be exposed to a staining agent **214** at least including a metal precursor **222** to form a metal-complexed block copolymer assembly **216** including at least one metal-complexed domain **218** and at least one non-metal-complexed domain **220**. The process may be substantially similar to that described above in relation to forming the metal-complexed block copolymer assembly **116**. The staining agent **214**, the metal-complexed block copolymer assembly **216**, the at least one metal-complexed domain **218**, and the at least one non-metal-complexed domain **220** may be substantially similar to the staining agent **114**, the metal-complexed block copolymer assembly **116**, the at least one metal-complexed domain **118**, and the at least one non-metal-complexed domain **120** described above, respectively.

Referring next to FIG. 2D, polymer material may be volatized and removed from the metal-complexed block copolymer assembly **216**, and the metal precursor **222** (FIG. 2C) in the at least one metal-complexed domain **218** (FIG. 2C) may be reduced to form at least one metal structure **224** over and in contact with the electrode **202**. The at least one metal structure **224** may be formed of a plurality of metal particles (not shown). Each metal particle of the plurality of metal particles may be discontinuous or discrete from each other metal particle of the plurality of metal particles. The process may be substantially similar to that described above in relation to forming the at least one metal structure **124**. The at least one metal structure **224** may be substantially similar to the at least one metal structure **124** described above. Conventional processes (e.g., electroless plating) may, optionally, be used to increase the size of the metal particles (not shown) of the at least one metal structure **224**.

The metal-complexed block copolymer assembly **216** (FIG. 2C) may, optionally, be exposed to an oxidizing agent before forming the at least one metal structure **224**. Exposure to the oxidizing agent may convert the metal precursor **222** (FIG. 1C) within the at least one metal-complexed domain **218** (FIG. 2C) to a metal oxide (not shown), which may then be reduced to metal by thermal anneal in a reducing atmosphere. The process may be substantially similar to that described above in relation to the treatment of the metal-complexed block copolymer assembly **116**. In additional embodiments, after exposing the metal-complexed block copolymer assembly **216** (FIG. 1C) to the oxidizing agent, the thermal anneal in the reducing atmosphere may be omitted, leaving a metal-oxide-complexed block copolymer assembly (not shown) including at least one metal-oxide-complexed domain (not shown) and at least one non-metal-oxide-complexed domain (not shown). Polymer of the metal-oxide-complexed block copolymer assembly (not shown) may be volatilized and removed (e.g., by way of a thermal anneal) to form at least one metal oxide structure.

As shown in FIG. 2E, an active material **204** may be formed over and in contact with the at least one metal structure **224** and the electrode **202**. The active material **204** may be substantially similar to the active material **104** described above, and may be formed using conventional techniques, such as CVD, PVD, or ALD, which are not described in detail herein. Referring to FIG. 2F, a structure **226**, such as an electrode or contact, may be formed over and in contact with the active material **204** at a position overlying the at least one metal structure **224**. The structure **226** may be formed using conventional deposition and patterning techniques, which are not described in detail herein. The structure **226** may be substantially similar to the structure **126** described above.

FIGS. 3A through 3E, are simplified partial cross-sectional views of a semiconductor device structure **300** illustrating embodiments of yet another method of forming at least one metal structure for a semiconductor device structure, such as an active electrode of a memory cell (e.g., for a CBRAM device), a conductive interface in a via, or a nucleation site. Referring to FIG. 3A, the semiconductor device structure **300** may include an electrode **302**, an active material **304**, and a polymer material **306**. The active material **304** may be formed over and in contact with the electrode **302**, and the polymer material **306** may be formed over and in contact with the active material **304**. The electrode **302** may be formed in, on, or over a substrate (not shown). In additional embodiments, the active material **304** may, at least initially, be omitted, and the polymer material **306** may be formed over and in contact with the electrode **302**.

The electrode **302** and the active material **304** may be substantially similar to the electrode **102** and the active material **104** described above, respectively. Each of the electrode **302** and the active material **304** may be formed using conventional techniques, such as PVD, CVD, or ALD. The polymer material **306** may be a homopolymer or a copolymer. As used herein, the term "homopolymer" means and includes a material resulting from the polymerization of a single monomeric species. The polymer material **306** may be capable of forming a complex with a metal precursor. The polymer material **306** may, by way of non-limiting example, be a hydrophilic polymer. In at least some embodiments, the polymer material **306** is poly-2-vinylpyridine (P2VP). The polymer material **306** may be formed over and in contact with the active material **304** by conventional techniques, such as grafting. As a non-limiting example, the polymer material **306** may be prepared with end groups (e.g., hydroxyl groups) that may interact (e.g., by forming covalent bonds) with the active material **304**.

Referring to FIG. 3B, a portion of the polymer material **306** (FIG. 3A) may be selectively removed to form a polymer

pattern **308** including at least one polymer structure **310** and at least one opening **312**. Removing the portion of the polymer material **306** (FIG. **3**A) may expose a surface of the active material **304** or, if the active material **304** is absent, a surface of the electrode **302**. The polymer pattern **308** may be formed using conventional techniques. By way of non-limiting example, a resist material (not shown), such as a conventional photoresist or a conventional e-beam resist, may be applied over the polymer material **306** (FIG. **3**A) and patterned using appropriate lithography techniques to form a patterned resist (not shown). The pattern defined by the patterned resist (not shown) may be transferred into the polymer material **306** (FIG. **3**A) using at least one dry etching process, such as reactive ion etching (RIE), plasma etching, reactive ion beam etching, or chemically assisted ion beam etching. Following the dry etching process, the patterned resist (not shown) may be removed using conventional techniques, such as a solvent strip utilizing a solvent with which the polymer is substantially immiscible. In additional embodiments, the polymer material **306** may be a stainable photoresist including a blend of photoactive species and chemically active species. The photoactive species may enable photoimaging, and the chemically active species may enable staining.

Referring next to FIG. **3**C, the polymer pattern **308** (FIG. **3**B) may be exposed to a staining agent **314** to form a metal-complexed polymer pattern **316** including at least one metal-complexed polymer structure **318** and the at least one opening **312**. The staining agent **314** and process of forming the metal-complexed polymer pattern **316** may be substantially similar to the staining agent **114** and process of forming of the metal-complexed copolymer assembly **116** described above. However, whereas the staining agent **114** may enable the selective coupling of the metal precursor **122** included therein with the polymer of the at least one minority domain **110**, the staining agent **314** may enable the selective coupling of metal precursor **322** included therein with the polymer of the at least one polymer structure **310** (FIG. **3**B).

Referring to FIG. **3**D, the polymer material may be volatized and removed from the at least one metal-complexed polymer structure **318** (FIG. **3**C), and the metal precursor **322** (FIG. **3**C) present therein may be reduced to form at least one metal structure **324** over and in contact with the active layer **304**. The process may be substantially similar to that described above with respect to the formation of the at least one metal structure **124**. The at least one metal structure **324** may be substantially similar to the at least one metal structure **124** described above and may be formed of a plurality of metal particles (not shown). Each metal particle of the plurality of metal particles may be discontinuous or discrete from each other metal particle of the plurality of metal particles. Conventional processes (e.g., electroless plating) may, optionally, used to increase the size of the metal particles (not shown) of the at least one metal structure **324**.

The at least one metal-complexed polymer structure **318** (FIG. **3**C) may, optionally, be exposed to an oxidizing agent before forming the at least one metal structure **324**. Exposure to the oxidizing agent may convert the metal precursor **322** (FIG. **3**C) within the at least one metal-complexed polymer structure **318** (FIG. **3**C) to a metal oxide (not shown), which may then be reduced to metal by thermal anneal in a reducing atmosphere. The process may be substantially similar to that described above in relation to the treatment of the metal-complexed block copolymer assembly **116**. In additional embodiments, after exposing the at least one metal-complexed polymer structure **318** (FIG. **3**C) to the oxidizing agent, the thermal anneal in the reducing atmosphere may be omitted, leaving at least one metal-oxide-complexed polymer structure (not shown). Polymer of the metal-oxide-complexed polymer structure (not shown) may be volatilized and removed (e.g., by way of a thermal anneal) to form at least one metal oxide structure.

In additional embodiments, such as where the active material **304** is initially omitted, the at least one metal structure **324** may be formed over and in contact with the electrode **302**, in a process substantially similar to that described above in relation to forming the at least one metal structure **224**. The active material **304** may then be formed over and in contact with the at least one metal structure **324** and the electrode **302**, in a process substantially similar to that described above in relation to forming the active material **204**.

Accordingly, a method of forming a memory cell may include forming a polymer material over an electrode. A portion of the polymer material may be removed to form a polymer pattern including at least one polymer structure and at least one opening. The polymer pattern may be exposed to a staining agent to form a metal-complexed polymer pattern including at least one metal-complexed polymer structure. The metal-complexed polymer pattern may be treated to form at least one metal structure.

Referring to FIG. **3**E, a structure **326**, such as an electrode or contact, may be formed over and in contact with the at least one metal structure **324**. The structure **326** may be formed using conventional deposition (e.g., CVD, ALD, or PVD) and patterning (e.g., masking and etching) techniques. The structure **326** may be substantially similar to the structure **126** described above. In additional embodiments, such as where the active material **304** is formed over and in contact with the at least one metal structure **324** and the electrode **302**, the structure **326** may be formed over and in contact with the active material **304** at a position overlying the at least one metal structure **324**, in a process substantially similar to that described above in relation to forming the structure **226**.

FIGS. **4**A through **4**G, are simplified partial cross-sectional views of a semiconductor device structure **400** illustrating embodiments of yet still another method of forming at least one metal structure for a semiconductor device structure, such as an active electrode of a memory cell (e.g., for a CBRAM device), a conductive interface in a via, or a nucleation site. Referring to FIG. **4**A, the semiconductor device structure **400** may include an electrode **402** and a patterned dielectric material **404**. The patterned dielectric material **404** may be formed over and in contact with the electrode **402**. The electrode **402** may be substantially similar to the electrode **102** described above, and may be formed in, on, or over a substrate (not shown) using conventional techniques, such as PVD, CVD, or ALD. The patterned dielectric material **404** may include at least one dielectric structure **406** and at least one opening **408**. The at least one opening **408** may be defined by a surface **405** of the electrode **404** and at least one sidewall **407** of the at least one dielectric structure **406**. The at least one dielectric structure **406** may, by way of non-limiting example, include at least one of silicon oxynitride (SiON), silicon nitride (Si_3N_4), silicon dioxide (SiO_2), another oxide material, and another polymer material. In at least some embodiments, the dielectric structure **406** is formed from Si_3N_4. The patterned dielectric material **404** may be formed using conventional deposition and patterning techniques, such as PVD, CVD, or ALD deposition followed by masking and etching. A conformal film of active material (not shown) may, optionally, be formed over and in contact with the patterned dielectric material **404** (e.g., the conformal film of active material may cover surfaces of the at least one dielectric structure **406** and the surface **405** of the electrode **404**). If present, the conformal film of active material (not shown) may be sub-

stantially similar to the active material **104** described above, and may be formed using conventional techniques, such as PVD, CVD, or ALD.

Referring next to FIG. **4**B, a polymer material **410** may be formed over and in contact with a surface **412** of the at least one dielectric structure **406**, the at least one sidewall **407** of the at least one dielectric structure **406**, and the surface **405** of the electrode **404** exposed by the at least one opening **408**. The polymer material **410** may cover or encompass the at least one dielectric structure **406** and may at least partially fill the at least one opening **408**. In at least some embodiments, the polymer material **410** substantially fills the at least one opening **408**. The polymer material **410** may be substantially similar to the polymer material **306** described above. In at least some embodiments, the polymer material **410** is P2VP. The polymer material **410** may be formed over and in contact with the patterned dielectric material **404** by conventional grafting techniques. As a non-limiting example, the polymer material **410** may be prepared with end groups (e.g., hydroxyl groups) that may interact (e.g., by forming covalent bonds) with one or more of the surface **412** of the at least one dielectric structure **406**, the at least one sidewall **407** of the at least one dielectric structure **406**, and the surface **405** of the electrode **404** exposed by the at least one opening **408**.

Referring to FIG. **4**C, a portion of the polymer material **410** (FIG. **4**B) may be removed to expose the surface **412** of the at least one dielectric structure **406** and form an assembly **414** including the at least one dielectric structure **406** and at least one polymer structure **416**. The portion of the polymer material **410** (FIG. **4**B) may be removed using conventional techniques, such as at least one of an abrasive planarization process (e.g., chemical mechanical planarization), and a suitable etching process (e.g., wet etching, dry etching).

Referring next to FIG. **4**D, the assembly **414** (FIG. **4**C) may be exposed to a staining agent **418** to form a metal-complexed assembly **420** including at least one metal-complexed polymer structure **422** and the at least one dielectric structure **406** (i.e., a non-metal-complexed structure). The staining agent **418** and process of forming the metal-complexed assembly **420** may be substantially similar to the staining agent **114** and process of forming of the metal-complexed copolymer assembly **116** described above. However, whereas the staining agent **114** may enable selective coupling of the metal precursor **122** included therein with the polymer of the at least one minority domain **110**, the staining agent **418** may enable the selective coupling of a metal precursor **426** included therein with the polymer of the at least one polymer structure **416** (FIG. **4**C).

In additional embodiments, the polymer material **410** (FIG. **4**B) may be exposed to the staining agent **418** to form a metal-complexed polymer material (not shown). A portion of the metal-complexed polymer material may then be removed to form the metal-complexed assembly **420** including the at least one metal-complexed polymer structure **422** and the at least one dielectric structure **406**.

Referring to FIG. **4**E, polymer material may be volatized and removed from the at least one metal-complexed polymer structure **422** (FIG. **4**D), and the metal precursor **426** (FIG. **4**D) present therein may be reduced to form at least one metal structure **428** over and in contact with the electrode **402**. The at least one metal structure **428** may be formed from a plurality of metal particles (not shown). Each metal particle of the plurality of metal particles may be discontinuous or discrete from each other metal particle of the plurality of metal particles. The process may be substantially similar to that described above in relation to forming the at least one metal structure **124**. However, as depicted in FIG. **4**E, the at least one dielectric structure **406** may remain following the process. The at least one metal structure **428** may be substantially similar to the at least one metal structure **124** described above. Conventional processes (e.g., electroless plating) may, optionally, be used to increase the size of the metal particles (not shown) of the at least one metal structure **428**.

The at least one metal-complexed polymer structure **422** (FIG. **4**D) may, optionally, be exposed to an oxidizing agent before forming the at least one metal structure **428**. Exposure to the oxidizing agent may convert the metal precursor **426** (FIG. **4**D) within the at least one metal-complexed polymer structure **422** (FIG. **4**D) to a metal oxide (not shown), which may then be reduced to metal by thermal anneal in a reducing atmosphere. The process may be substantially similar to that described above in relation to the treatment of the metal-complexed block copolymer assembly **116**. In additional embodiments, after exposing the at least one metal-complexed polymer structure **422** (FIG. **4**D) to the oxidizing agent, the thermal anneal in the reducing atmosphere may be omitted, leaving at least one metal-oxide-complexed polymer structure (not shown). Polymer of the metal-oxide-complexed polymer structure (not shown) may be volatilized and removed (e.g., by way of a thermal anneal) to form at least one metal oxide structure.

Referring next to FIG. **4**F, an active material **430** may be formed over and in contact with the at least one metal structure **428** and the at least one dielectric structure **406**. The active material **430** may be formed using conventional techniques, such as CVD, PVD, or ALD. The active material **430** may be substantially similar to the active material **104** described above. In additional embodiments, the active material **430** may be selectively formed over and in contact with the at least one metal structure **428** (e.g., the active material **430** may be selectively grown on the at least one metal structure **428**). As shown in FIG. **4**G, a structure **432**, such as an electrode or contact, may be formed over and in contact with at least a portion of the active material **430** at a position overlying the at least one metal structure **428**. The structure **432** may be substantially similar to the second electrode **126** described above, and may be formed using conventional deposition (e.g., CVD, ALD, or PVD) and patterning (e.g., masking and etching) techniques. At least a portion of the structure **432** may also contact the at least one dielectric structure **406**.

FIGS. **5**A through **5**F are simplified partial cross-sectional views of a semiconductor device structure **500** illustrating embodiments of yet still an additional method of forming at least one metal structure for a semiconductor structure, such as an active electrode of a memory cell (e.g., for a CBRAM device), a conductive interface in a via, or a nucleation site. Referring to FIG. **5**A, the semiconductor structure **500** include an electrode **502**, and a patterned dielectric material **504**. The electrode **502** may be a conductive material (e.g., W, WN, Ni, TaN, Pt, Au, TiN, TiSiN, TiAlN, or MoN) that is reactive with a polymer material to be grafted on a surface **510** thereof, as described in further detail below. The patterned dielectric material **504** may include at least one dielectric structure **506** and at least one opening **508**. The at least one opening **508** may be defined by the surface **510** of the electrode **502** and at least one sidewall **511** of the dielectric structure **506**. The at least one dielectric structure **506** may be a dielectric material (e.g., amorphous carbon) that is non-reactive with the polymer material to be grafted on the surface **510** of electrode **502**, as described in further detail below.

Referring next to FIG. **5**B, a polymer material **512** may be selectively grafted over and in contact with the surface **510** of the electrode **502** exposed by the at least one opening **508** to

form an assembly **505** including the polymer material **512** and the dielectric structure **506**. The polymer material **512** may be substantially similar to the polymer material **306** described above. In at least some embodiments, the polymer material **512** is P2VP. The polymer material **512** may be selectively grafted over and in contact with the portion of the surface **510** by conventional grafting techniques. As a non-limiting example, the polymer material **512** may be prepared with end groups (e.g., hydroxyl groups) that may interact (e.g., by forming covalent bonds) with the surface **510** of the electrode **502**. The dielectric structure **506** may be substantially non-reactive with the polymer material **512** such that the polymer material **512** does not become grafted to the at least one sidewall **511** of the dielectric structure **506**. A suitable rinse may, optionally, be performed to remove portions of the polymer material **512** not grafted to the surface **510** of the electrode **502**.

Referring to FIG. **5**C, the assembly **505** (FIG. **5**B) may be exposed to a staining agent **514** to form a metal-complexed assembly **516** including at least one metal-complexed polymer structure **518** and the at least one dielectric structure **506** (i.e., a non-metal-complexed structure). The staining agent **514** and process of forming the metal-complexed assembly **516** may be substantially similar to the staining agent **114** and process of forming of the metal-complexed copolymer assembly **116** described above. However, whereas the staining agent **114** may enable selective coupling of the metal precursor **122** included therein with the polymer of the at least one minority domain **110**, the staining agent **514** may enable the selective coupling of a metal precursor **520** included therein with the polymer of the at least one polymer material **512** (FIG. **5**B).

Referring to FIG. **5**D, polymer material may be volatized and removed from the at least one metal-complexed polymer structure **518** (FIG. **5**C), and the metal precursor **520** (FIG. **5**C) present therein may be reduced to form at least one metal structure **522** over and in contact with the electrode **502**. The at least one metal structure **522** may include a plurality of metal particles (not shown). Each metal particle of the plurality of metal particles may be discontinuous or discrete from each other metal particle of the plurality of metal particles. Conventional processes (e.g., electroless plating) may, optionally, be used to increase the size of the metal particles (not shown) of the at least one metal structure **522**. The process of forming the metal structure **522** may be substantially similar to that described above with respect to the formation the at least one metal structure **124**. However, as depicted in FIG. **5**D, the at least one dielectric structure **506** may remain following the process.

The at least one metal-complexed polymer structure **518** (FIG. **5**C) may, optionally, be exposed to an oxidizing agent before forming the at least one metal structure **522**. Exposure to the oxidizing agent may convert the metal precursor **520** (FIG. **5**C) within the at least metal-complexed polymer structure **518** (FIG. **5**C) to a metal oxide (not shown), which may then be reduced to metal by thermal anneal in a reducing atmosphere. The process may be substantially similar to that described above in relation to the treatment of the metal-complexed block copolymer assembly **116**. In additional embodiments, after exposing the at least one metal-complexed polymer structure **518** (FIG. **5**C) to the oxidizing agent, the thermal anneal in the reducing atmosphere may be omitted, leaving at least one metal-oxide-complexed polymer structure (not shown). Polymer of the at least one metal-oxide-complexed polymer structure (not shown) may be volatilized and removed (e.g., by way of a thermal anneal) to form at least one metal oxide structure.

Accordingly, a method of forming a memory cell may include forming a patterned dielectric material including at least one dielectric structure and at least one opening over an electrode. A polymer material may be formed over and in contact with at least a surface of the electrode exposed by the at least one opening. The at least one dielectric structure and the polymer material may be exposed to a staining agent to form a metal-complexed assembly including at least one metal-complexed polymer structure. The metal-complexed assembly may be treated to form at least one metal structure.

Referring next to FIG. **5**E, an active material **524** may be formed over and in contact with the at least one metal structure **522** and the at least one dielectric structure **506**. The active material **524** may be formed using conventional techniques, such as CVD, PVD, or ALD. The active material **524** may be substantially similar to the active material **104** described above. In additional embodiments, the at least one dielectric structure **506** may be removed and the active material **524** may be formed over and in contact with the at least one metal structure and the electrode **502**. As shown in FIG. **5**F, a structure **526**, such as an electrode or contact, may be formed over and in contact with at least a portion of the active material **524** at a position overlying the at least one metal structure **522**. The structure **526** may be substantially similar to the structure **126** described above, and may be formed using conventional deposition (e.g., CVD, ALD, or PVD) and patterning (e.g., masking and etching) techniques. At least a portion of the structure **526** may also contact the at least one dielectric structure **506**, if present.

The methods of the present disclosure advantageously reduce metal processing, decrease material deposition variability relative to conventional selective deposition technologies, such as electroless plating, and enable the formation of semiconductor structures, memory cells, and semiconductor devices that exhibit increased reliability, performance, and durability. In addition, the methods of the present disclosure enable the deposition of material on electrochemically inactive materials (e.g., dielectric materials, such as oxide materials) where conventional selective deposition technologies, such as electroless plating, may be substantially ineffective. Structures (e.g., metal structures, or metal oxide structures) may be formed in desired locations on a substantially planar material (e.g., an electrode (i.e., a conductive material) or an active material), or in openings in a patterned material (e.g., a patterned dielectric material) that overlies a substantially planar material.

The following examples serve to explain embodiments of the present disclosure in more detail. The examples are not to be construed as being exhaustive or exclusive as to the scope of the disclosure.

EXAMPLES

Example 1

Two solutions of 1% P2PV in 10:1 tetrahydrofuran:diemthylformamide were prepared. One solution included 10 wt % copper(II) chloride ($CuCl_2$). The other solution included 2 wt % $CuCl_2$. Coupon samples were prepared by spin-coating the solutions onto a substrate stack including silicon ("Si", 95 Å), a pad oxide layer ("PADOX", 300 Å), nitride (30 Å), and zirconium oxide ("ZrOx"). Samples including each of the above concentrations of $CuCl_2$ were thermally annealed for 10 minutes at 750° C. under an atmosphere of either ammonia (NH_3) or 3.8% hydrogen (H_2) in argon (Ar) according to Table 2 below.

TABLE 2

Sample Data		
Sample	wt % $CuCl_2$	Reducing atmosphere
F	10	H_2
H	10	NH_3
J	2	H_2
L	2	NH_3

After the thermal anneal the samples were inspected by scanning electron micrograph (SEM), Auger electron spectroscopy, and XPS. SEM imagery of samples F, H, and J showed the formation of white particles. FIG. **6**A is a scanning electron micrograph (SEM) image showing a top-down view of white particles formed from the sample F. FIG. **6**B is a magnified SEM image showing a top-down view of a single white particle formed from sample F illustrating the two areas used for Auger analysis. The chart of Auger analysis of sample F is shown in FIG. **7**A. Particles formed from samples H and J had similar results. An Auger electron map of the white particle shown in FIG. **6**B is shown in FIG. **7**B. The XPS analysis results are shown in Table 3 below. In Table 3, samples 1, 2, 3, and 4 respectively correspond to samples F, H, J, and L of Table 2. The Auger and XPS analysis results showed that the white particles formed from sample F (i.e., sample 1 in Table 3 below) were copper and had both CuO and either Cu_2O or Cu(0) metal composition. No chlorine atoms were detected, indicating that the particles were fully reduced and then subsequently re-oxidized by atmospheric oxygen. The particles formed from samples F, H, J, and L had center diameters ranging from about 50 nm to about 250 nm.

TABLE 3

XPS Analysis Data								
	Surface elemental concentrations (in atom %)							
Sample	C	N	O	F	So	Zr	Cu(o)/Cu(I)	Cu(II)
1	14.8	8.6	49.0	0.5	8.4	16.4	0.8	1.5
2	39.9	3.0	32.5	10.3	3.2	11.2	ND	ND
3	16.2	7.4	49.5	0.5	8.3	18.0	ND	ND
4	32.2	2.7	44.3	0.6	7.0	13.2	ND	ND

Example 2

Two solutions of 1% PS-P2PV in 10:1 tetrahydrofuran: diemthylformamide were prepared. One solution included 10 wt % copper(II) chloride ($CuCl_2$). The other solution included 2 wt % $CuCl_2$. Coupon samples were prepared by spin-coating the solutions onto a substrate stack including Si (95 Å), PADOX (300 Å), nitride (30 Å), and ZrOx. Two samples, one for each of the above concentrations of $CuCl_2$, were thermally annealed for 10 minutes at 750° C. under an atmosphere of 3.8% hydrogen (H_2) in argon (Ar).

After the thermal anneal the samples was inspected by scanning electron micrograph (SEM) and Auger electron spectroscopy. SEM imagery for each of the sample including 10 wt % $CuCl_2$ loading and the sample including 2 wt % $CuCl_2$ loading show the formation of white particles. FIGS. **8**A and **8**B are SEM images (i.e., at 10 k and 100 k magnification, respectively) showing a top-down view of white particles formed from the sample including 10 wt % $CuCl_2$ loading. FIGS. **9**A and **9**B are SEM images (i.e., at 10 k and 100 k magnification, respectively) showing a top-down view of white particles formed from the sample including 2 wt % $CuCl_2$ loading. The sample including 10 wt % $CuCl_2$ loading exhibited a greater areal density of white particles, and formed particle center diameters ranging from about 20 nm to about 100 nm. The sample including 2 wt % $CuCl_2$ loading exhibited separated clusters of white particles, and formed particle center diameters of about 50 nm. FIG. **10**A is a scanning electron micrograph (SEM) image showing a top-down view of white particles formed from a sample B including 2 wt % $CuCl_2$. FIG. **10**B is a magnified SEM image showing a top-down view of a single white particle formed from sample B illustrating the two areas used for Auger analysis. The chart of Auger analysis of sample B is shown in FIG. **11**A. An Auger electron map of the white particle shown in FIG. **10**B is shown in FIG. **11**B. The Auger analysis results showed that the white particles formed from sample B were copper.

While the present disclosure is susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, the present disclosure is not intended to be limited to the particular forms disclosed. Rather, the present disclosure is to cover all modifications, equivalents, and alternatives falling within the scope of the present disclosure as defined by the following appended claims and their legal equivalents.

What is claimed is:

1. A method of forming a semiconductor device structure, comprising:
- forming a block copolymer assembly comprising at least two different domains over an electrode;
- selectively coupling at least one metal precursor to the block copolymer assembly to form a metal-complexed block copolymer assembly comprising at least one metal-complexed domain and at least one non-metal-complexed domain; and
- annealing the metal-complexed block copolymer assembly to form at least one metal structure over the electrode.

2. The method of claim **1**, wherein forming a block copolymer assembly comprises:
- applying a block copolymer material comprising at least two different polymer blocks over the electrode; and
- separating the at least two different polymer blocks to form the at least two different domains, each of the domains comprising at least one of the different polymer blocks.

3. The method of claim **1**, wherein forming the block copolymer assembly comprises forming the block copolymer assembly such that at least one of the at least two different domains extends linearly along a direction normal to a planar surface of the electrode.

4. The method of claim **1**, further comprising forming an active material between the electrode and the block copolymer assembly.

5. The method of claim **1**, further comprising forming a structure comprising at least one of a metal, a metal alloy, and a metal oxide over and in contact with the at least one metal structure.

6. The method of claim **1**, further comprising:
- forming an active material comprising a solid state electrolyte material over the at least one metal structure and the electrode; and
- forming a structure over the active material at a position overlying the at least one metal structure.

7. The method of claim **1**, wherein selectively coupling the at least one metal precursor to the block copolymer assembly comprises exposing the block copolymer assembly to a stain-

ing agent comprising a solvent and at least one of an elemental metal, an elemental metalloid, and a metal-containing compound.

8. The method of claim **7**, wherein exposing the block copolymer assembly to the staining agent comprises exposing the block copolymer assembly to an aqueous acid solution comprising a metal-containing compound having anionic functionality.

9. The method of claim **8**, wherein exposing the block copolymer assembly to the staining agent comprises exposing the block copolymer assembly to an aqueous base solution comprising a metal-containing compound having cationic functionality.

10. The method of claim **1**, wherein selectively coupling at least one metal precursor to the block copolymer assembly comprises exposing the block copolymer assembly to a staining agent comprising at least one of a copper compound and a silver compound.

11. The method of claim **1**, wherein annealing the metal-complexed block copolymer assembly comprises exposing the metal-complexed block copolymer assembly to a temperature within a range of from about 250° C. to about 750° C. in a reducing atmosphere.

12. The method of claim **1**, wherein the at least one metal structure comprises a plurality of metal particles.

13. The method of claim **1**, further comprising exposing the metal-complexed block copolymer assembly to an oxidizing agent before annealing the metal-complexed block copolymer assembly.

14. The method of claim **1**, wherein forming a block copolymer assembly comprises:

applying a block copolymer material comprising a hydrophilic block and a hydrophobic block over the electrode; and

phase-separating the hydrophilic block and the hydrophobic block to form a hydrophilic domain and a hydrophobic domain.

15. The method of claim **1**, wherein forming a block copolymer assembly comprises:

applying polystyrene-block-poly-2-vinylpyridine over the electrode; and

annealing the polystyrene-block-poly-2-vinylpyridine.

16. The method of claim **1**, wherein forming a block copolymer assembly comprises forming one of the at least two different domains to have cationic functionality, and wherein selectively coupling at least one metal precursor to the block copolymer assembly comprises exposing the block copolymer assembly to at least one of silver (I) nitrate and copper (I) chloride.

17. The method of claim **1**, wherein forming a block copolymer assembly comprises forming one of the at least two different domains to have anionic functionality, and wherein selectively coupling at least one metal precursor to the block copolymer assembly comprises exposing the block copolymer assembly to at least one of ammonium silver (I) thiosulfate and copper (II) chloride.

18. The method of claim **1**, wherein selectively coupling the at least one metal precursor to the block copolymer assembly comprises exposing the block copolymer assembly to a staining agent comprising at least one of copper, silver, ruthenium, cobalt, nickel, titanium, tungsten, tantalum, molybdenum, platinum, palladium, iridium, gold, iron, silicon, and germanium.

19. The method of claim **1**, wherein annealing the metal-complexed block copolymer assembly comprises exposing the metal-complexed assembly to a reducing atmosphere and a temperature greater than or equal to a decomposition temperature of polymer material of the metal-complexed block copolymer assembly.

20. The method of claim **1**, further comprising exposing the metal-complexed block copolymer assembly to at least one of air, oxygen, nitrogen dioxide, water, nitrous oxide, dinitrogen tetroxide, and ozone before annealing the metal-complexed block copolymer assembly.

21. The method of claim **1**, further comprising:

forming an active material comprising at least one of a chalcogenide compound, a transition metal oxide, and a silicon oxide on the at least one metal structure and the electrode; and

forming at least one structure on the active material at a position overlying the at least one metal structure.

22. A method of forming a semiconductor device structure, comprising:

forming a block copolymer assembly over an electrode, the block copolymer assembly comprising:

a first domain formulated to interact with a metal precursor through at least one of chelation, other ligand interactions, and coulombic interactions; and

a second domain formulated to not interact with the metal precursor through at least one of chelation, other ligand interactions, and coulombic interactions;

exposing the block copolymer assembly to the metal precursor to form a metal-complexed assembly comprising a metal-complexed domain and a non-metal-complexed domain; and

treating the metal-complexed assembly to form at least one of a metal structure and a metal oxide structure over the electrode.

23. The method of claim **22**, wherein forming a block copolymer assembly comprises forming the first domain to comprise unsaturated organic groups and at least one element of Groups VA and VIA of the Periodic Table of Elements.

24. The method of claim **22**, wherein forming a block copolymer assembly comprises forming the first domain to comprise a polymer having pyridine functional groups.

25. The method of claim **22**, wherein forming a block copolymer assembly comprises forming the first domain to comprise poly(vinylpyridine).

26. The method of claim **22**, wherein forming a block copolymer assembly comprises forming the first domain to comprise a polymer having at least one of carboxylic acid groups and thiol groups.

27. The method of claim **22**, wherein forming a block copolymer assembly comprises forming the first domain to comprise poly((meth)acrylic acid).

28. The method of claim **22**, wherein forming a block copolymer assembly comprises forming the second domain to comprise polystyrene.

29. The method of claim **22**, wherein treating the metal-complexed assembly comprises annealing the metal-complexed assembly to form the metal structure over the electrode.

30. The method of claim **22**, wherein treating the metal-complexed assembly comprises:

exposing the metal-complexed assembly to an oxidizing agent to form a metal-oxide-complexed block copolymer assembly; and

annealing the metal-oxide-complexed block copolymer assembly to form the metal oxide structure over the electrode.

* * * * *