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**Morgan et al.**

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(54) **INSULATION MATERIALS COMPRISING FIBERS HAVING A PARTIALLY CURED POLYMER COATING THEREON, ARTICLES INCLUDING SUCH INSULATION MATERIALS, AND METHODS OF FORMING SUCH MATERIALS AND ARTICLES**

(58) **Field of Classification Search**  
USPC ..... 428/36.1, 221  
See application file for complete search history.

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(57) **ABSTRACT**

Insulation materials have a coating of a partially cured polymer on a plurality of fibers, and the plurality of coated fibers in a cross-linked polymeric matrix. Insulation may be formed by applying a preceramic polymer to a plurality of fibers, heating the preceramic polymer to form a partially cured polymer over at least portions of the plurality of fibers, disposing the plurality of fibers in a polymeric material, and curing the polymeric material. A rocket motor may be formed by disposing a plurality of coated fibers in an insulation precursor, curing the insulation precursor to form an insulation material without sintering the partially cured polymer, and providing an energetic material over the polymeric material. An article includes an insulation material over at least one surface.

**18 Claims, 4 Drawing Sheets**

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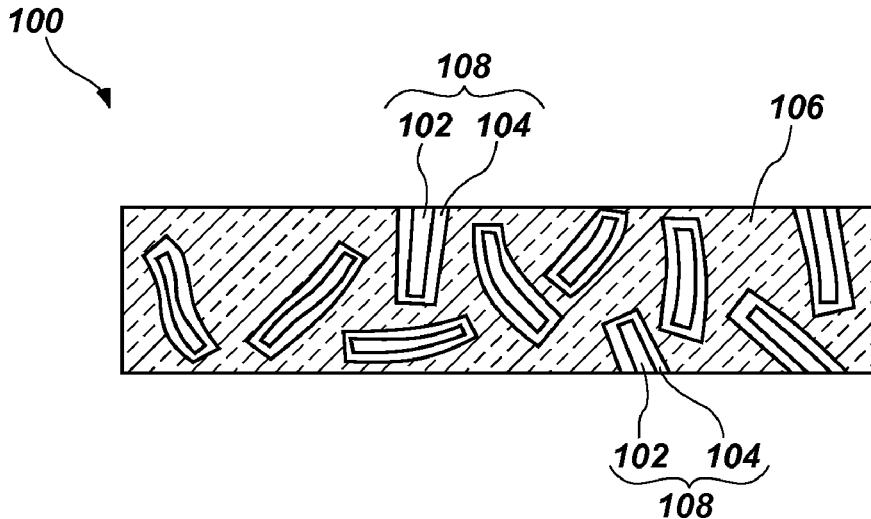
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**C04B 35/00** (2006.01)  
**F02K 1/82** (2006.01)  
**F02K 9/32** (2006.01)  
**H01B 3/30** (2006.01)

(52) **U.S. Cl.**

CPC ..... **F02K 9/00** (2013.01); **C04B 35/00** (2013.01); **F02K 1/822** (2013.01); **F02K 9/32** (2013.01); **H01B 3/308** (2013.01); **F05D 2300/6033** (2013.01); **Y10T 428/1362** (2015.01); **Y10T 428/249921** (2015.04); **Y10T 442/2631** (2015.04)



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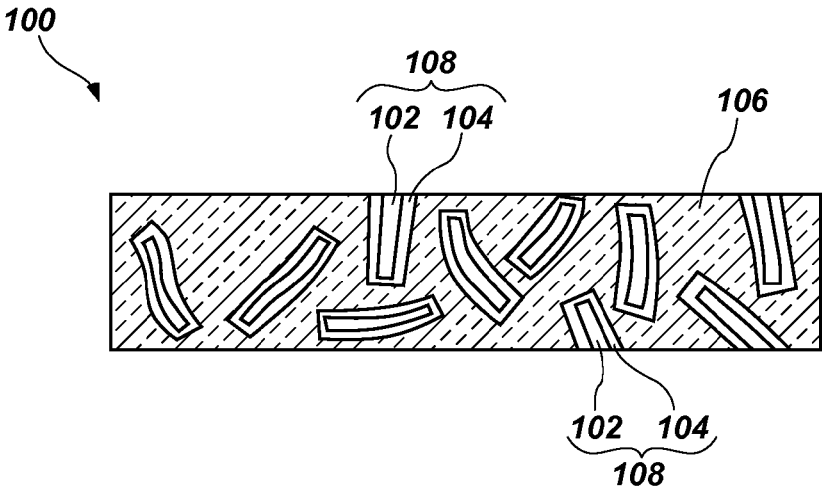


FIG. 1

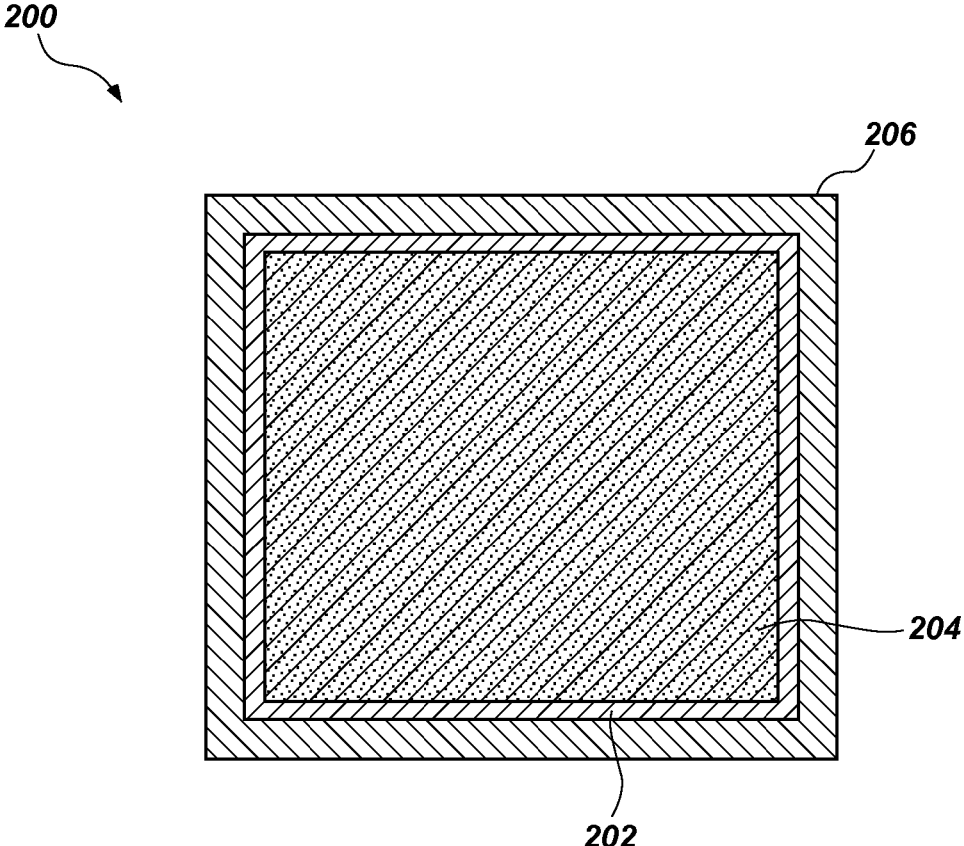


FIG. 2

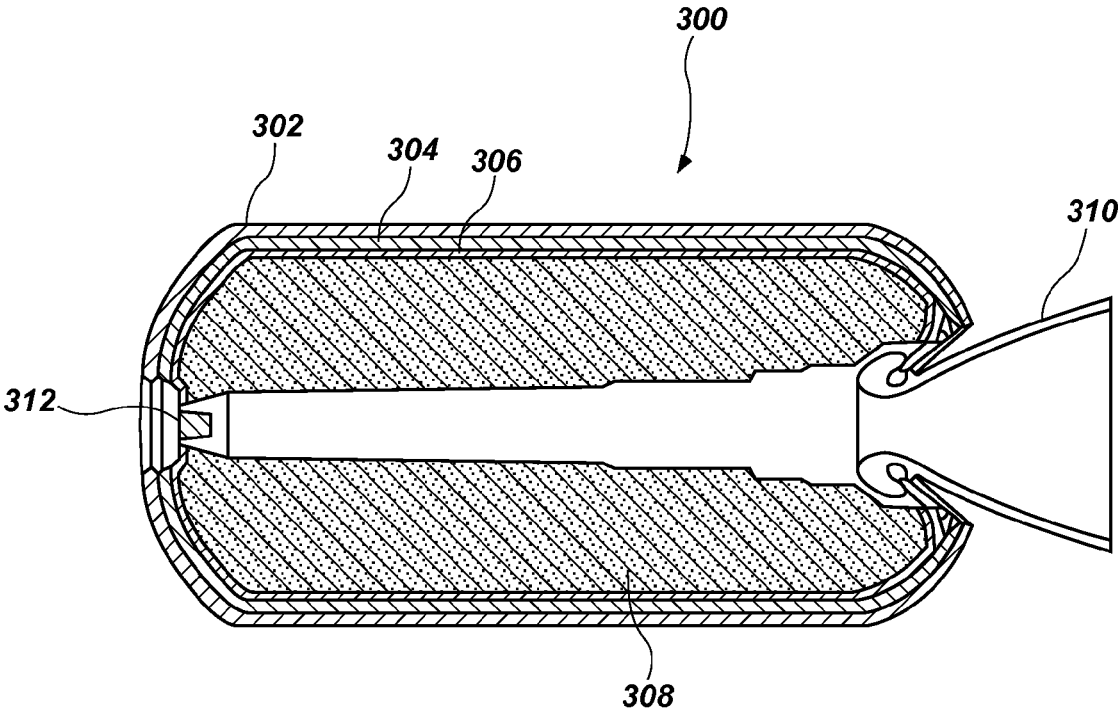


FIG. 3

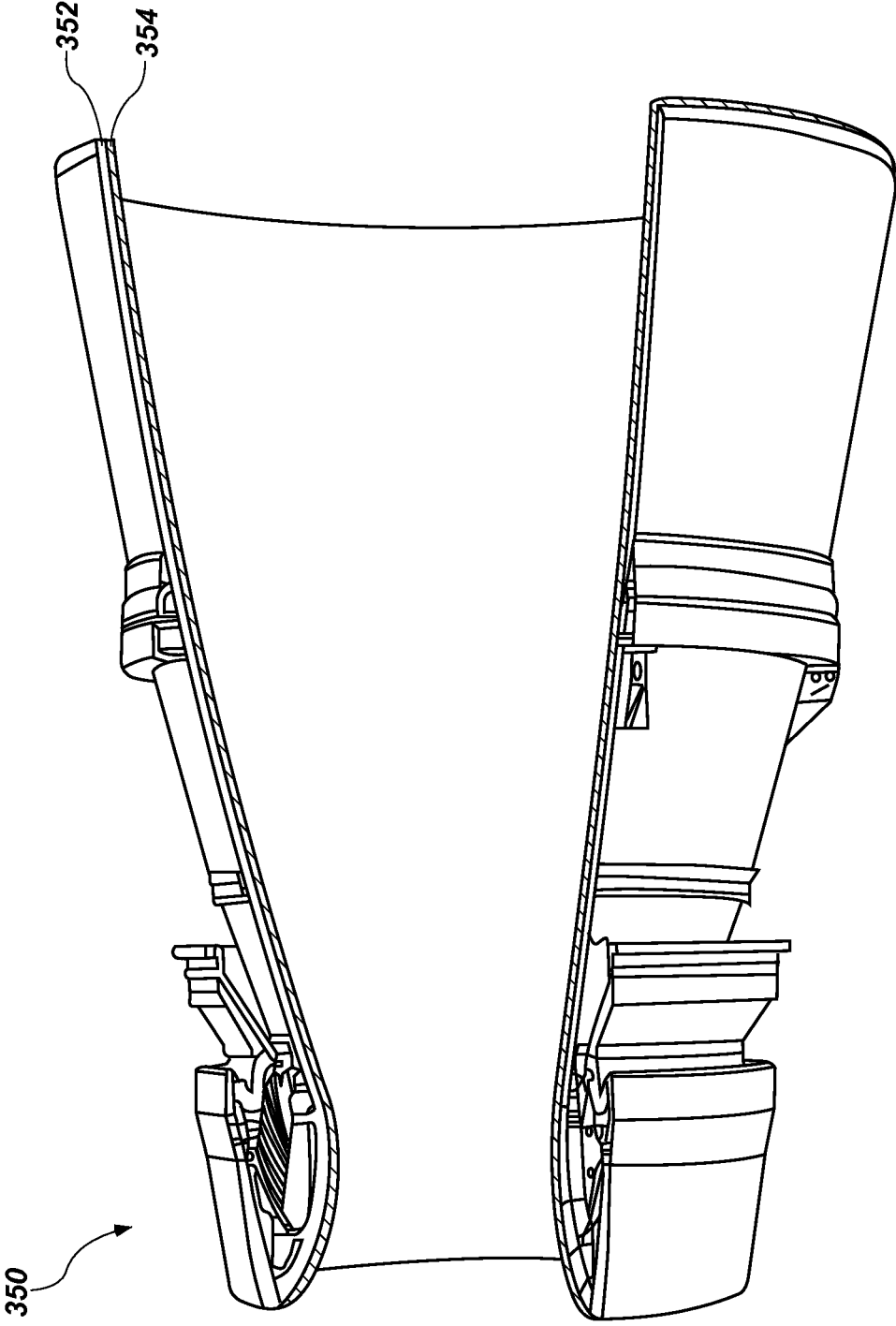


FIG. 4

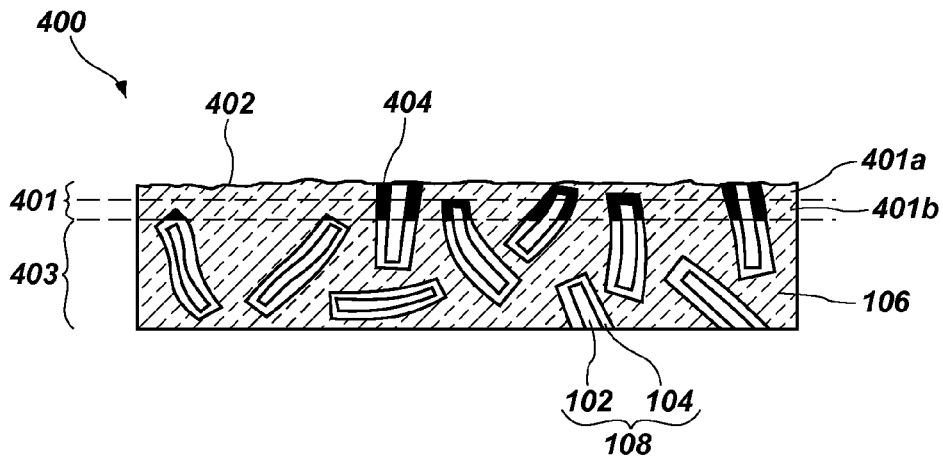


FIG. 5

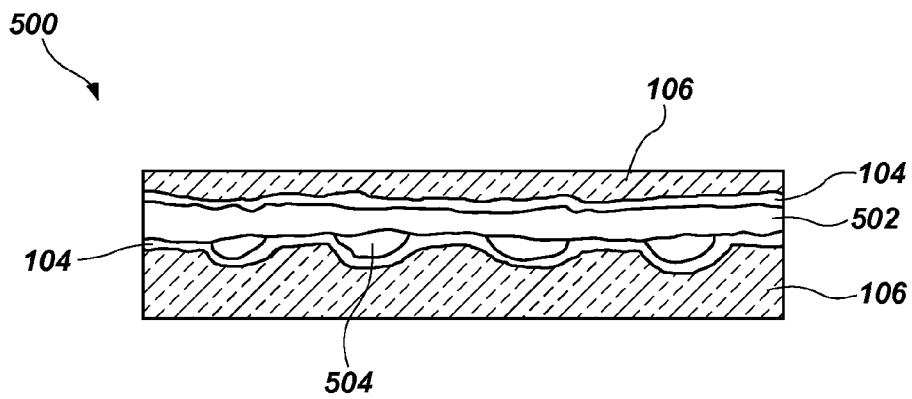


FIG. 6

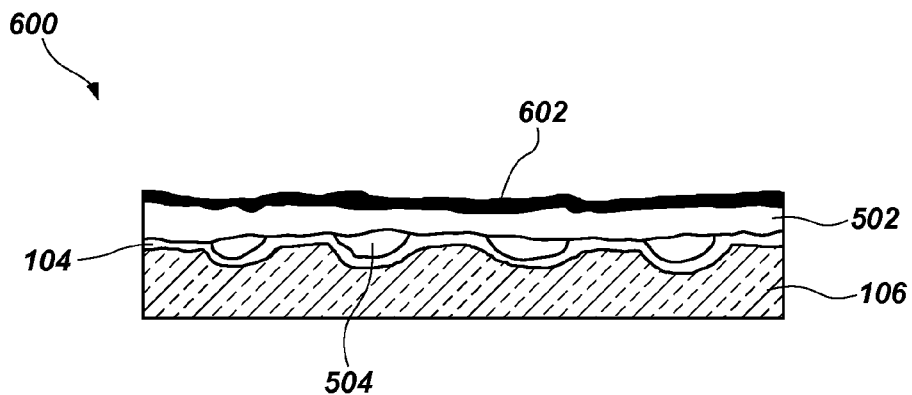


FIG. 7

**INSULATION MATERIALS COMPRISING  
FIBERS HAVING A PARTIALLY CURED  
POLYMER COATING THEREON, ARTICLES  
INCLUDING SUCH INSULATION  
MATERIALS, AND METHODS OF FORMING  
SUCH MATERIALS AND ARTICLES**

GOVERNMENT LICENSE RIGHTS

This invention was made with government support under Contract No. NNM11AA01B, Task Order NNM12AA33T, awarded by NASA, and Contract No. ABL W31P4Q-08-D-0026, awarded by the Army. The government has certain rights in the invention.

TECHNICAL FIELD

Embodiments of the present disclosure relate to insulation materials, articles including the insulation materials, and methods of forming the insulation materials and articles. Insulation materials of embodiments of the present disclosure exhibit increased thermal resistivity compared to conventional insulation.

BACKGROUND

Solid rocket motors include energetic and non-energetic materials. Improving the performance of a solid rocket motor typically requires increasing the performance of the energetic material, increasing the mass of energetic material, decreasing the mass of the non-energetic material, or some combination of these modifications. Because solid rocket motors are volume-limited systems, reducing the volume of non-energetic materials in the solid rocket motor allows for an increase in the volume and mass of energetic materials.

The non-energetic materials in a rocket motor may include, for example, a casing, insulation material, liner materials formulated to promote bonding, and nozzle materials. Reducing the volume of the insulation material may leave a relatively larger volume within the rocket motor, but may also leave the casing with insufficient thermal protection. Thus, in the design of rocket motors, performance and thermal protection are considered together in attempting to develop an optimized system within known parameters.

Rocket motor casings are generally made of metal, a composite material, or a combination of metal and composite materials. During operation, insulation protects the rocket motor casing from thermal effects and erosive effects of particle streams generated by combustion of a propellant. Typically, the insulation is bonded to the interior surface of the casing and is fabricated from a composition that, upon curing, is capable of enduring the high temperature gases and erosive particles produced while the propellant burns. A liner bonds the propellant to the insulation and to any noninsulated interior surface portions of the casing. Liners also typically have an ablative function, inhibiting burning of the insulation at liner-to-insulation interfaces.

The combustion of a solid rocket propellant generates extreme conditions within the rocket motor casing. For example, temperatures inside the rocket motor casing can reach 2,760° C. (5,000° F.). These conditions, in combination with the restrictive throat region of the nozzle passage-way, create a high degree of turbulence of high-temperature combustion gases within the rocket motor casing and nozzle. In addition, gases produced during propellant combustion typically contain high-energy particles that, under a turbulent environment such as encountered in a rocket motor, can

erode the rocket motor insulation. If gases produced by the burning propellant penetrate the insulation and liner, the casing may melt or otherwise be compromised, causing the rocket motor to fail. Thus, the insulation is formulated to withstand the extreme conditions experienced during propellant combustion and protect the casing from the burning propellant.

Some conventional rocket motor insulations include filled and unfilled plastics or polymers, such as phenolic resins, epoxy resins, high temperature melamine-formaldehyde coatings, as well as ceramics, polyester resins, and the like. Plastics, however, tend to crack or blister in response to the rapid heat and pressure fluctuations experienced during rocket motor propellant combustion.

Rubbers and elastomers have also been used as rocket motor insulation. Cured ethylene-propylene-diene monomer ("EPDM") terpolymer may be used alone or in a blend, and is often selected because of its favorable mechanical, thermal, and ablative properties. However, in high-velocity environments, the ablative properties of elastomers are sometimes inadequate for rocket motor operation unless the elastomers are reinforced with suitable fillers, such as carbon fibers or silica fibers. The criticality of avoiding high erosion rates is demonstrated by the severity and magnitude of risk of failure due to erosion. Most insulation is, of necessity, "man-rated" in the sense that a catastrophic failure can result in the loss of human life. Additionally, the tensile strength and tear strength of unfilled elastomers may not be sufficiently high to withstand and endure the mechanical stresses that the elastomer is subjected to during processing.

Incorporation of fibers can increase the ablation resistance of an insulation material. However, many fibers are friable, and degrade during the preparation of the insulation material.

It would be advantageous to provide a thermal protection system that occupies less volume than conventional insulation materials. Such thermal protection may make it possible to increase the volume loading of energetic material in a rocket motor, increasing the performance of the motor. Such thermal protection may also be useful to make advanced propellant formulations feasible (e.g., propellants that burn hotter than conventional propellants).

BRIEF SUMMARY

Some embodiments of the present disclosure include insulation materials having a plurality of fibers with a partially cured polymer coating thereon and disposed in a cross-linked polymeric matrix.

Some methods of forming insulation materials include applying a preceramic polymer to a plurality of fibers, heating the preceramic polymer to form a partially cured polymer over at least portions of the plurality of fibers, disposing the plurality of fibers in a polymeric material, and curing the polymeric material.

A method of forming a rocket motor includes coating a plurality of fibers with a partially cured polymer formulated to form a ceramic upon exposure to a temperature of at least 850° C., disposing the plurality of coated fibers in an insulation precursor, curing the insulation precursor to form a polymeric material without sintering the partially cured polymer, and providing an energetic material over the polymeric material.

In some embodiments, an article includes an insulation material over at least one surface. The insulation material

includes a plurality of fibers coated with a partially cured polymer, the plurality of coated fibers dispersed in a cross-linked polymeric matrix.

#### BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the invention, advantages of the present disclosure may be more readily ascertained from the following detailed description when read in conjunction with the accompanying drawings in which:

FIG. 1 shows a simplified schematic cross-section of an insulation material according to an embodiment of the present disclosure;

FIG. 2 shows a simplified cross-section of an article including an insulation material according to an embodiment of the present disclosure;

FIG. 3 shows a simplified cross-section of a rocket motor including an insulation material according to an embodiment of the present disclosure;

FIG. 4 shows a simplified cutaway view of a rocket motor nozzle including an insulation material according to an embodiment of the present disclosure;

FIG. 5 shows a simplified schematic cross-section of the insulation material of FIG. 1 after exposure to a temperature of greater than about 850° C.;

FIG. 6 shows a simplified schematic cross-section of another insulation material according to an embodiment of the present disclosure; and

FIG. 7 shows a simplified schematic cross-section of the insulation material of FIG. 6 after exposure to a temperature of greater than about 850° C.

#### DETAILED DESCRIPTION

Insulation materials, insulated articles, methods of forming insulation materials and insulated articles, and methods of firing rocket motors having the insulation materials are described. In one embodiment, an insulation material includes fibers coated with a partially cured polymer. The coated fibers are in a cross-linked polymeric matrix. The cross-linked polymeric matrix may be a conventional insulation material. When the insulation material is exposed to high temperatures, such as those that occur during a rocket-motor firing, the partially cured polymer forms a ceramic on the insulation material that increases the insulative properties of the insulation. The insulation material of embodiments of the present disclosure may provide increased thermal protection to an article containing the insulation material.

As used herein, the term “partially cured polymer” means and includes a crosslinked polymeric compound produced from a polymeric precursor of a ceramic (a preceramic polymer). The partially cured polymer is formed by partially curing the preceramic polymer at a temperature sufficient to promote crosslinking among carbons of the preceramic polymer but not sufficient to ceramify the preceramic polymer. The process of forming the partially cured polymer may be referred to in the art as “staging,” “partially curing,” “polymerizing,” or “green-curing.” Thus, the partially cured polymer is a material that has not been sintered to form ceramic.

The insulation material may include a cross-linked polymeric material. The cross-linked polymeric material may be a cured solid, and may include polymers used to form conventional insulation materials. For example, the cross-

linked polymeric material may be polyisoprene, EPDM terpolymer, nitrile butadiene rubber (NBR), hydroxyl-terminated polybutadiene (HTPB) rubber, etc. The cross-linked polymeric material may also include a filler dispersed therein, such as silica, clay, carbon black, asbestos, or polyvinyl chloride. Depending on the desired properties, the insulation material may optionally include other components, such as antioxidants, cure accelerators, cure activators, tackifiers, and/or plasticizers. Such components are known in the art and, therefore, are not described in detail herein.

The insulation material also includes a plurality of fibers within a matrix of the cross-linked polymeric material. The fibers are coated with the partially cured polymer. Fibers may be in bulk form (independent of one another) or in sheets of material (e.g., woven fabric). The fibers may be, for example, aramid fibers (e.g., KEVLAR® brand fibers, available from E.I. du Pont de Nemours and Company, of Wilmington, Del.), carbon fibers, etc. The coated fibers may be within the continuous solid matrix of cross-linked polymeric material.

The partially cured polymer on the fibers may be a material formulated to form a ceramic upon exposure to a relatively high temperature. For example, the partially cured polymer may form a ceramic, such as silicon carbide, silicon nitrocarbide, or silicon oxycarbide, at a temperature above about 850° C., above about 1000° C., or even above about 1200° C. In its partially cured state, the partially cured polymer may have a rubberlike consistency. Thus, the coating of the partially cured polymer on the fibers may be flexible until the partially cured polymer is ceramified. Due to the high sintering temperature of the preceramic polymer, the partially cured polymer may remain less than fully cured during and after the continuous solid matrix is formed and cured. For example, in some embodiments, the continuous solid matrix may be formed by curing the cross-linked polymeric material at a temperature of about 200° C. or lower, well below a sintering temperature of the partially cured polymer. The partially cured polymer may include a silicon-based, preceramic polymer, such as an organosilicon polymer that produces a silicon carbide, silicon nitrocarbide, or silicon oxycarbide when ceramified. For example, the partially cured polymer may be a polycarbosilane, a polysilazane, a polysiloxane, or combinations thereof. The partially cured polymer may be formed by a low-temperature cure (e.g., a cure at a temperature from about 180° C. to about 400° C.) of the preceramic polymer. The preceramic polymer may be a liquid at a temperature at which the preceramic polymer is applied to the fibers. For example, the preceramic polymer may be a one-component liquid precursor to silicon carbide, such as STARPCS® SMP-10, available from Starfire Systems, of Schenectady, N.Y. Some preceramic polymers are described in U.S. Pat. No. 7,714, 092, issued May 11, 2010, and titled “Composition, Preparation of Polycarbosilanes and Their Uses.” The coating of the partially cured polymer may have a mean thickness over the fibers of less than the mean diameter of the fibers. For example, the fibers may have a mean diameter from about 0.01 mm to about 1 mm. In such embodiments, the coating of the partially cured polymer may have a mean thickness from about 0.001 mm to about 0.2 mm. Thus, the coating of the partially cured polymer may account for a small percentage of a total weight of the insulation material.

FIG. 1 shows a simplified illustration of an insulation material **100**. The insulation material **100** has a plurality of fibers **102** coated with a partially cured polymer **104**. The coated fibers **108** are in a cross-linked polymeric matrix **106**.



The insulation material **100** may be formed by coating fibers **102** with the preceramic polymer (a first polymeric material), then heating the fibers **102** and the preceramic polymer to a temperature sufficient to partially cure or green-cure the preceramic polymer to form the partially cured polymer **104**. The preceramic polymer may be applied to the fibers **102** by conventional techniques, which are not described in detail herein. The coated fibers **108** may include a substantially continuous coating of the partially cured polymer **104** over the fibers **102** or may include a discontinuous coating of the partially cured polymer **104** over the fibers **102**. In some embodiments, the fibers **102** and the preceramic polymer may be maintained at a temperature from about 100° C. to about 300° C., at atmospheric pressure, and less than about 10% relative humidity for a time period sufficient to polymerize the preceramic polymer. For example, the fibers **102** and the preceramic polymer may be maintained at a temperature of at least about 150° C. for a time period from about 30 minutes to about 60 minutes. The degree of curing of the preceramic polymer may be a function of the cure conditions (e.g., temperature, humidity, pressure, etc.) and the cure time. The coated fibers **108** may then be mixed with or coated with a precursor of the cross-linked polymeric matrix **106**, which may be a second polymeric material or a monomeric material. For example, the coated fibers **108** may be mixed with a precursor used to form polyisoprene, EPDM terpolymer, NBR, HTPB rubber, etc. In some embodiments, a sheet or cloth formed of the fibers **102** may be coated with the partially cured polymer **104**, then coated with a precursor of the cross-linked polymeric matrix **106**. The coated fibers **108** and the precursor may be heated to a temperature sufficient to cure the precursor to form the cross-linked polymeric matrix **106**. The cure temperature may be selected such that the precursor cures without further curing, sintering, decomposing, or otherwise modifying the chemical structure of the partially cured polymer **104**. In some embodiments, the precursor may be maintained at a temperature from about 100° C. to about 300° C. in a press for a time period sufficient to cross-link or polymerize the precursor. For example, the coated fibers **108** and the precursor may be maintained at a temperature of about 150° C. for a time period from about 30 minutes to about 60 minutes to form the cross-linked polymeric matrix **106**. A cure catalyst may be added to the precursor to promote the curing thereof. The concentration of the cure catalyst may be tailored to effect formation of a material with selected physical properties (e.g., hardness, strength, ductility, etc.). The precursor may be cured in an oven maintained at approximately constant temperature, pressure, and/or humidity.

The insulation material **100** may be applied to a surface (e.g., a surface of a rocket motor, a nozzle, or another body) after the insulation material **100** is formed or the insulation material **100** may be applied to a surface in-situ. For example, the insulation material **100** may be formed into sheets, and the sheets may be bonded to a surface, or may be strip-wrapped over a surface. In some embodiments, insulation precursors (e.g., a precursor to the cross-linked polymeric matrix **106** with coated fibers **108** dispersed therein) may be applied to a surface, such as by spin-coating, spreading, etc., and the insulation precursors may be cured to form the insulation material **100**.

As shown in FIG. 2, an article **200** may include an insulation material **202** (e.g., the insulation material **100** shown in FIG. 1) and an energetic composition **204** (e.g., a propellant composition, a gas generator composition, a smokeless gun powder composition, a munitions composi-

tion, an explosive composition, etc.). The insulation material **202** and the energetic composition **204** may be contained within a housing **206** of the article **200**. By way of example, the article **200** may include a gas generating device, such as an airbag device or a fire suppression device, ordnance, munitions, or a rocket motor. The article **200** may also include, but is not limited to, cartridges for small arms ammunition (e.g., rimfire cartridges, center fire cartridges, shot shells, rifled slugs, etc.), grenades, mines, mortar fuses, detcord initiators, illuminating flares, or signaling flares.

As shown in FIG. 3, a rocket motor **300** may include insulation materials according to embodiments of the present disclosure. For example, a rocket motor **300** may include a casing **302**, an insulation material **304** (e.g., the insulation material **100** shown in FIG. 1), a liner **306**, and an energetic material **308** (e.g., a solid propellant such as a double-base propellant, an HTPB-based propellant, etc.). The insulation material **304** may include the fibers coated with the partially cured polymer in the cured polymeric matrix. The rocket motor **300** may also include a nozzle assembly **310**, an igniter **312**, etc.

The rocket motor **300** may be formed by securing the insulation material **304** within the casing **302** by conventional techniques. For example, the insulation material **304** may be formed within the casing **302** or may be formed as one or more sheets, which are subsequently bonded to the casing **302**. The insulation material **304** may be formed as described above with respect to the insulation material **100** of FIG. 1. The liner **306** is provided over at least a portion of the insulation material **304** and the casing **302**. The energetic material **308** is provided (e.g., cast) into the casing **302** over the liner **306**.

As shown in FIG. 4, a nozzle **350** may include insulation materials according to embodiments of the present disclosure. For example, a nozzle **350** may include an outer wall **352** and an insulation material **354** (e.g., the insulation material **100** shown in FIG. 1). The outer wall **352** may include a material formulated to provide a physical structure over which the insulation material **354** is formed. For example, the outer wall **352** may include a metal or a composite material. The insulation material **354** may include the fibers coated with the partially cured polymer in the cured polymeric matrix. For example, the insulation material **354** may include a sheet or fabric of the fibers coated with the partially cured polymer, and over which the polymeric matrix (e.g., a phenolic resin) is formed and cured.

The insulation materials **100**, **202**, **304**, **354** disclosed herein and shown in FIGS. 1 through 4 may exhibit improved insulative properties when exposed to temperatures sufficient to cause the partially cured polymer **104** (FIG. 1) to form a ceramic. For example, when one side of the insulation material **100** is exposed to a temperature sufficient to modify the chemical structure of the partially cured polymer **104**, a ceramic may form. FIG. 5 illustrates an insulation material **400** that has been subjected to a high temperature (e.g., greater than about 850° C.) along a surface **402** of the insulation material **400**. The insulation material **400** has the fibers **102** coated with the partially cured polymer **104** in the cross-linked polymeric matrix **106**, as shown in FIG. 1 and described above. Following exposure to the high temperature, the insulation material **400** forms two regions: a heat-affected region **401** and a virgin material region **403**. The heat-affected region **401** may include two sub-regions: an ablated region **401a** and a char region **401b**. The ablated region **401a** may include ash that is easily removed from the insulation material **400**. The char region **401b** may include a crust of material that is adhered

to the virgin material region **403**. A portion of the cross-linked polymeric matrix **106** in the ablated region **401a** may be removed during exposure to the high temperature. Furthermore, a portion of the partially cured polymer **104** in the heat-affected region **401** reacts or fuses to form a ceramic **404** over or around the fibers **102**. The ceramic **404** provides additional insulative properties to the insulation material **400**.

Since the partially cured polymer **104** includes a silicon-based preceramic polymer, the ceramic **404** formed during exposure of the insulation material **400** to a high temperature may be an inorganic ceramic, such as a glass material. In some embodiments, the ceramic **404** may include silicon dioxide, silicon carbide, or a combination thereof. The ceramic **404** may be substantially free of carbon. In some embodiments, the ceramic **404** may include some carbon, but inorganic materials of the ceramic **404** may form a sintered matrix. The ceramic **404** may be tenacious in that it remains adhered to the insulation material **400** during use and operation of an article, such as the article **200** (FIG. 2), the rocket motor **300** (FIG. 3), or the nozzle **350** (FIG. 4). Without being bound to any particular theory, the ceramic **404** may form by sintering of the partially cured polymer **104** to remove carbon from the solid structure. For example, the carbon of the partially cured polymer **104** (see FIG. 1) may be removed in the form of low-molecular-weight organic materials and combustion products of carbon (e.g., carbon dioxide). Gases, such as hydrogen, nitrogen, carbon dioxide, or carbon monoxide, may form and diffuse away from the surface **402**. The reaction of the partially cured polymer **104** may leave a portion of inorganic material (e.g., a layer of inorganic material) over a portion of the fibers **102** or the cross-linked polymeric matrix **106**. The ceramic **404** may adhere or cling to the fibers **102** or the cross-linked polymeric matrix **106**, such that the ceramic **404** remains at the surface **402** of the insulation material **400** and provides resistance to heat transfer through the insulation material **400**. The ceramic **404** may remain on the surface **402** of the insulation material **400** when exposed to gas turbulence.

The ceramic **404** may have a higher thermal reflectivity (defined as the radiation reflected by a surface divided by the radiation received by a surface) than the cross-linked polymeric matrix **106** or the partially cured polymer **104**. Thus, upon formation of the ceramic **404**, which is a glassy material, the insulation material **400** may reflect more thermal energy than the insulation material **100** (FIG. 1) lacking the ceramic **404**. Thus, the ceramic **404** may improve the ability of the insulation material **400** to protect surfaces from extreme temperatures.

Returning to FIG. 3, the rocket motor **300** may be used to propel a vehicle (e.g., a rocket). The igniter **312** may be activated to ignite the energetic material **308** within the casing **302**. The burning energetic material **308** may heat the interior of the casing **302**, including the energetic material **308**, the liner **306**, and the insulation material **304**. Combustion of the energetic material **308** exposes the insulation material **304** to hot gases. For example, combustion of the energetic material **308** may form gases at temperatures of about 1200° C. or higher, about 1800° C. or higher, or even about 2400° C. or higher. The gases ablate a portion of the cross-linked polymeric matrix **106** and a portion of the partially cured polymer **104** forms ceramic **404** (see FIG. 5). The ceramic **404** may reflect a portion of the heat back into the interior of the casing **302**, heating the energetic material **308** (thus increasing the burn rate thereof) and maintaining the casing **302** at a lower temperature than may be observed absent ceramic formation. The nozzle **350** shown in FIG. 4

may offer similar benefits, forming a ceramic over the insulation material **354** as hot gases pass through the nozzle **350**, especially near the throat, where the highest flow velocity typically occurs. The ceramic may decrease the flow of thermal energy to the outer wall **352** of the nozzle **350**.

FIG. 6 shows a simplified illustration of an embodiment of insulation material **500**. The insulation material **500** has a plurality of fibers **502** and **504** formed into cloths or sheets of material. For example, the fibers **502** and **504** may be knit or woven. The fibers **502** and **504** are coated with the partially cured polymer **104**. The fibers **502** and **504** are in the cross-linked polymeric matrix **106**.

After the insulation material **500** has been subjected to a high temperature (e.g., greater than about 850° C.), the insulation material **600** shown in FIG. 7 may form. Upon exposure to the high temperature, a portion of the cross-linked polymeric matrix **106** is ablated. Furthermore, a portion of the partially cured polymer **104** reacts or fuses to form a ceramic **602** over or around the fibers **502** and **504**. The ceramic **602** provides additional insulative properties to the insulation material **600**. The ceramic **602** may form a continuous layer over the fibers **502** and **504**.

The formation of the ceramic over an insulation material during a rocket motor firing may be beneficial because the ceramic may have a higher volume or thermal resistivity than the insulation material from which the ceramic forms. Formation of ceramic may also limit or prevent ablation of the insulation material by reflecting heat because the ceramic may be more reflective than the cross-linked polymeric matrix **106**.

Ceramic materials in general may function well as insulators. However, insulation materials containing ceramics tend to be relatively expensive and have less robust physical properties (e.g., may be more brittle) than other insulation materials. Forming a ceramic material from a partially cured polymer during use and operation of the article (e.g., during exposure to heat, such as in a rocket motor firing) may provide the benefits of having a ceramic material in the insulation material, yet may limit or minimize problems associated with the ceramic material being present in the insulation material initially. For example, forming a ceramic during use may limit the risk that the ceramic will be damaged (e.g., cracked) during manufacturing or handling of an article. Any damage to the ceramic during use may be healed by subsequent formation of additional ceramic material. Thus, insulation materials having partially cured polymers therein may have better insulating properties than conventional materials.

By increasing the thermal performance of an insulation material, the volume of the insulation material may be reduced in comparison to conventional insulation materials, leaving a larger volume of the article available to contain energetic or other materials. All other factors being equal, the performance of a rocket motor may be increased by increasing the volume of energetic material. The volume of energetic material may be increased by replacing a portion of non-energetic insulation material with energetic material, so long as the remaining insulation material provides sufficient thermal protection.

Furthermore, by coating the fibers with preceramic polymers as described herein, the amount of partially cured polymers and ceramic material may account for a small portion of the insulation material, saving on costs and insulation weight. Since the ceramic material is present as a coating on the fibers, the ceramic material may contribute

only a small amount to the overall weight to the insulation material and, thus, to the cost of the insulation material.

Because the coated fibers disclosed herein may be used in a matrix of various insulation materials, the matrix may be selected to have a long useful life (e.g., by retaining physical properties in storage conditions). Lifecycle costs may be decreased by increasing the lifetime of the insulation material, which further decreases the costs of production (e.g., of replacement components), logistics, and disposal (e.g., of old, unusable components).

The insulation materials disclosed herein may enhance safety of handling and use of energetic compositions and related components. The insulation materials disclosed herein may be used in conjunction with any energetic composition, such as solid propellants, gas generators, smokeless powders, explosives, igniters, etc. The insulation materials may provide protection from degradation of the casing or other enclosure during the use of the energetic composition, which may be valuable in protecting against catastrophic failure.

The insulation materials may be used as a drop-in replacement for conventional insulation materials in the production of rocket motors and other devices. For example, the insulation material may be used in automotive air-bag deployment systems, fire walls, fire-fighting equipment, etc. The insulation materials may be particularly useful for protecting from extremely high temperatures for short periods of time.

The following examples serve to explain embodiments of the insulation materials and methods of forming the insulation materials in more detail. These examples are not to be construed as being exhaustive or exclusive as to the scope of the disclosure.

EXAMPLES

Materials mentioned in the following Examples are available from the commercial sources indicated, including The Dow Chemical Company (Midland, Mich.), E.I. du Pont de Nemours and Company (Wilmington, Del.), Akrochem Corporation (Akron, Ohio), Vanderbilt Chemicals, LLC (Norwalk, Conn.), PPG Industries, Inc. (Monroeville, Pa.), Cabot Corporation (Boston, Mass.), Horsehead Corporation (Monaca, Pa.), and S.F. Sulfur Corporation (Freeport, Tex.). Percentages in the following examples are weight percentages based on the total composition mixture. The ingredients of these examples are also summarized in Table 2 below.

Insulation materials were tested using the Plasma Torch Test Bed (PTTB) at NASA's Marshall Space Flight Center. The PTTB includes a plasma torch (Model 7 MB, available from Metco) attached to a mechanical beam or arm. For each test, a square of insulation to be tested was prepared having dimensions of about 5.1 cm by about 5.1 cm. A heat flux gauge was placed adjacent the square of insulation, and was

used to calibrate the torch on each test. A water-spray fume hood in the test bay was configured to trap any noxious gases produced during the test.

The test included weighing and measuring the thickness of the insulation before placing the insulation in a sample holder. The plasma torch was directed toward the heat flux gauge to measure the heat output of the torch. The torch was then adjusted as necessary (e.g., by changing the distance from the torch to the gauge or the amount of fuel or air entering the torch) to obtain a selected flux. Once the appropriate flux was obtained, the torch was moved over the insulation sample, e.g., in the same plane as the heat flux gauge. After exposure to a selected heat flux for a selected period of time, the insulation material was cooled, the ash or ablated material was removed, and the remaining insulation material (including the char) was weighed and its thickness measured. The char was then removed, and the weight and thickness measurements were repeated. The testing method and apparatus are described in R. E. Morgan et al., "Non-Asbestos Insulation Testing Using a Plasma Torch," AIAA Paper 2000-3317 (American Institute of Aeronautics and Astronautics 2000).

A summary of the silica-filled EPDM (SFEPDM) insulation materials formed and tested in the PTTB is shown in Table 1.

TABLE 1

Insulation materials tested in Examples			
Example	Insulation type	Change in thickness (mils)	Observed?
1	SFEPDM without fibers	1	No
1	SFEPDM without fibers	2	No
2	SFEPDM with carbon fibers	-2	No
2	SFEPDM with carbon fibers	0	No
3	SFEPDM with graphite fibers	0	No
3	SFEPDM with graphite fibers	0	No
4	SFEPDM with KEVLAR® fibers	4	No
4	SFEPDM with KEVLAR® fibers	1	No
5	SFEPDM with coated carbon fibers	-3	No
5	SFEPDM with coated carbon fibers	11	Yes
6	SFEPDM with coated graphite fibers	33	Yes
6	SFEPDM with coated graphite fibers	-1	No
7	SFEPDM with coated KEVLAR® fibers	19	Yes
7	SFEPDM with coated KEVLAR® fibers	8	Yes

Example 1

SFEPDM Insulation without Fibers

A sulfur-cured insulation material (silica-filled EPDM) was formed having the composition shown in Table 2.

TABLE 2

Composition of silica-filled EPDM			
Material	Trade Name	Source	Weight %
ethylene-propylene-diene terpolymer (EPDM)	NORDEL™ IP 4640	Dow Chem.	33.05
ethylene-propylene-diene terpolymer (EPDM)	NORDEL™ IP 4520	Dow Chem.	26.44
chlorosulfonated polyethylene	HYPALON® 20	DuPont	6.61
thermoplastic-phenolic resin-tackifier	AKROCHEM® P-133	Akrochem Corp.	3.30
octylated diphenylamines	AGERITE® STALITE® S	Vanderbilt Chem.	1.32
amorphous silicon dioxide	HI-SIL™ 233	PPG Industries	23.46
carbon black	HAF Carbon Black	Cabot Corp.	0.33

TABLE 2-continued

Composition of silica-filled EPDM			
Material	Trade Name	Source	Weight %
zinc oxide	KADOX ® 930	Horsehead Corp.	2.64
magnesium oxide	ELASTOMAG ® 170	Akrochem Corp.	0.33
mercaptobenzothiazole disulfide	ALTAX ® MBTS	Vanderbilt Chem.	0.99
(1,1'(hexadithiocarbonothioyl)bis-piperidine)	SULFADS ®	Vanderbilt Chem.	0.20
bis(dibutylcarbomethioato-S,S') zinc sulfur	BUTYL ZIMATE ® Laccofine Sulfur	Vanderbilt Chem. S.F. Sulfur Corp.	0.99 0.33

The insulation material was mixed by hand, spread into a sheet approximately 3 mm thick, then cured in a press for 60 minutes at about 150° C. The cured insulation material was measured and tested in the PTTB under a heat flux of about 600 BTU/ft<sup>2</sup> s (about 6,800 kJ/m<sup>2</sup> s). The plume of gases directed at the insulation material in the PTTB included alumina particles at a mass concentration of about 0.03%.

The PTTB test was performed in duplicate. After the tests, the thickness of the insulation was measured, and the insulation materials were found to be 1 mil (0.001 inch or 0.025 mm) and 2 mils (0.002 inch or 0.051 mm) thicker, respectively, than before the tests. During a typical test, the thickness of insulation can increase due to swelling of insulation material and the formation of char or ceramic. The thickness can decrease due to ablation of the surface of the insulation material by the plume. The measurement of the change in thickness indicates the combined effect of these factors.

#### Example 2

##### SFEPDM Insulation with Carbon Fiber Cloth

The insulation material of Example 1 (before curing) was applied over and around a carbon-fiber fabric tape (available from Fiberglass Supply, of Burlington, Wash.). The insulation material was cured and tested in duplicate as described in Example 1.

After the tests, the thickness of the insulation was measured. One sample of the insulation materials was found to be 2 mils thinner than before the tests. No change in thickness was observed for the other sample.

#### Example 3

##### SFEPDM Insulation with Graphite Fiber Cloth

The insulation material of Example 1 (before curing) was applied over and around a graphite-fiber cloth (available from Fiberglass Supply). The insulation material was cured and tested in duplicate as described in Example 1.

After the tests, the thickness of the insulation was measured. No change in thickness was observed for either sample.

#### Example 4

##### SFEPDM Insulation with Aramid Fiber Cloth

The insulation material of Example 1 (before curing) was applied over and around an aramid-fiber (KEVLAR®) cloth (available from Fiberglass Supply). The insulation material was cured and tested in duplicate as described in Example 1.

After the tests, the thickness of the insulation was measured. The insulation materials were found to be 4 mils and 1 mil thicker, respectively, than before the tests.

#### Example 5

##### SFEPDM Insulation with Coated Carbon Fiber Cloth

A carbon-fiber fabric tape (available from Fiberglass Supply) was coated with a silicon carbide preceramic polymer (STARPCS® SMP-10, available from Starfire Systems, of Schenectady, N.Y.) by applying the silicon carbide preceramic polymer over the cloth, draining the excess preceramic polymer, and heating the cloth in an oven maintained at 150° C., less than 5 torr, and less than 10% relative humidity for 60 minutes. The heating formed the preceramic polymer into a cross-linked silicon carbide polymer coating over the cloth. The insulation material of Example 1 (before curing) was applied over and around the coated carbon-fiber cloth. The insulation material was cured and tested in duplicate as described in Example 1.

In one test, a flash was observed, in which the energy of the plasma torch was reflected from the surface of the insulation. Without being bound to any particular theory, it is believed that the flash corresponded to formation of a ceramic surface over the insulation material. After the tests, the thickness of the insulation was measured. The insulation material in the test having the flash was found to be 11 mils thicker than before the test. The insulation material in the test without a flash was found to be 3 mils thinner than before the test.

Without being bound to any particular theory, it is believed that insulation materials that did not exhibit a flash may have been deformed in the PTTB apparatus such that the heat flux was not properly focused. This may have prevented the insulation from reaching a temperature at which the ceramic material would have formed. An observed flash appears to correlate with formation of a relatively thick ceramic. Because the silicon carbide preceramic polymer forms silicon carbide at temperatures above about 850° C., exposure of the insulation materials having coated fibers to temperatures below 850° C. should not cause the formation of ceramic material.

#### Example 6

##### SFEPDM Insulation with Coated Graphite Fibers

A graphite fiber cloth (available from Fiberglass Supply) was coated with a silicon carbide preceramic polymer (STARPCS® SMP-10) by applying the silicon carbide preceramic polymer over the cloth, draining the excess preceramic polymer, and heating the cloth in an oven maintained

at 150° C., atmospheric pressure, and less than 10% relative humidity for 60 minutes. The heating formed the preceramic polymer into a cross-linked silicon carbide polymer coating over the cloth. The insulation material of Example 1 (before curing) was applied over and around the coated graphite-fiber cloth. The insulation material was cured and tested in duplicate as described in Example 1.

In one test, a flash was observed, in which the energy of the plasma torch was reflected from the surface of the insulation. After the tests, the thickness of the insulation was measured. The insulation material in the test having the flash was found to be 33 mils thicker than before the test. The insulation material in the test without a flash was found to be 1 mil thinner than before the test.

Without being bound to any particular theory, it is believed that insulation materials that did not exhibit a flash may have been deformed in the PTTB apparatus such that the heat flux was not properly focused. This may have prevented the insulation from reaching a temperature at

## Prophetic Example 8

## EPDM Insulation with Coated Aramid Fibers

An aramid-fiber is coated with a silicon carbide preceramic polymer (STARPCS® SMP-10) by applying the silicon carbide preceramic polymer over the cloth, draining the excess preceramic polymer, and heating the cloth in an oven maintained at 150° C., atmospheric pressure, and less than 10% relative humidity for 60 minutes. The heating forms the preceramic polymer into a cross-linked silicon carbide polymer coating over the cloth. A sulfur-cured insulation material (EPDM) is formed having the composition shown in Table 3. The composition shown in Table 3 is similar to the composition shown in Table 2, above, but without the amorphous silicon dioxide. Alternatively, the EPDM insulation may be formed with another filler material.

TABLE 3

Composition of EPDM			
Material	Trade Name	Source	Weight %
ethylene-propylene-diene terpolymer (EPDM)	NORDEL™ IP 4640	Dow Chem.	43.19
ethylene-propylene-diene terpolymer (EPDM)	NORDEL™ IP 4520	Dow Chem.	34.54
chlorosulfonated polyethylene	HYPALON® 20	DuPont	8.64
thermoplastic-phenolic resin-tackifier	AKROCHEM® P-133	Akrochem Corp.	4.31
octylated diphenylamines	AGERITE® STALITE® S	Vanderbilt Chem.	1.72
carbon black	HAF Carbon Black	Cabot Corp.	0.43
zinc oxide	KADOX® 930	Horsehead Corp.	3.45
magnesium oxide	ELASTOMAG® 170	Akrochem Corp.	0.43
mercaptobenzothiazole disulfide	ALTAX® MBTS	Vanderbilt Chem.	1.29
(1,1'(hexadithiocarbonothioyl)bis-piperidine)	SULFADS®	Vanderbilt Chem.	0.26
bis(dibutylcarbamodithioato-S,S') zinc sulfur	BUTYL ZIMATE® Laccofine Sulfur	Vanderbilt Chem. S.F. Sulfur Corp.	1.29 0.43

which the ceramic material would have formed. An observed flash appears to correlate with formation of a relatively thick ceramic. Because the silicon carbide preceramic polymer forms silicon carbide at temperatures above about 850° C., exposure of the insulation materials having coated fibers to temperatures below 850° C. should not cause the formation of ceramic material.

## Example 7

## SFEPDM Insulation with Coated Aramid Fibers

An aramid-fiber (KEVLAR®) cloth (available from Fiberglass Supply) was coated with a silicon carbide preceramic polymer (STARPCS® SMP-10) by applying the silicon carbide preceramic polymer over the cloth, draining the excess preceramic polymer, and heating the cloth in an oven maintained at 150° C., atmospheric pressure, and less than 10% relative humidity for 60 minutes. The heating formed the preceramic polymer into a cross-linked silicon carbide polymer coating over the cloth. The insulation material of Example 1 (before curing) was applied over and around the coated aramid-fiber cloth. The insulation material was cured and tested in duplicate as described in Example 1.

In both tests, a flash was observed, in which the energy of the plasma torch was reflected from the surface of the insulation. The insulation materials were found to be 19 mils and 8 mils thicker, respectively, than before the tests.

The sulfur-cured insulation material is applied over and around the coated aramid-fiber cloth.

## Prophetic Example 9

## NBR Insulation with Coated Aramid Fibers

An aramid-fiber (KEVLAR®) cloth is coated with a polysilazane silicon carbide preceramic polymer by applying the silicon carbide preceramic polymer over the cloth, draining the excess preceramic polymer, and heating the cloth in an oven maintained at 150° C., atmospheric pressure, and less than 10% relative humidity for 60 minutes. The heating forms the preceramic polymer into a cross-linked silicon-nitrogen coating over the cloth. A nitrile butadiene rubber (NBR) is formed having copolymers of acrylonitrile and butadiene, such as NIPOL® 1042, NIPOL® 1052, NIPOL® 1052-30, NIPOL® 1312, or combinations thereof, commercially available from Zeon Chemicals (Louisville, Ky.). The NBR is applied over and around the coated aramid-fiber cloth.

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

## 15

the scope of the present invention as defined by the following appended claims and their legal equivalents.

What is claimed is:

1. An insulation material, comprising:  
a plurality of fibers comprising a partially cured preceramic polymer coating thereon and disposed in a cross-linked polymeric matrix, wherein a preceramic polymer of the partially cured preceramic polymer coating comprises a material selected from the group consisting of a polycarbosilane, a polysilazane, a polysiloxane, and combinations thereof.
2. The insulation material of claim 1, wherein the preceramic polymer of the partially cured preceramic polymer coating comprises a polycarbosilane.
3. The insulation material of claim 1, wherein the partially cured preceramic polymer coating is formulated to form a ceramic upon exposure to a temperature of at least about 850° C.
4. The insulation material of claim 1, wherein the cross-linked polymeric matrix comprises a cured solid material.
5. The insulation material of claim 1, wherein the cross-linked polymeric matrix comprises at least one material selected from the group consisting of polyisoprene, ethylene propylene diene monomer, nitrile butadiene rubber, and hydroxyl-terminated polybutadiene.
6. The insulation material of claim 1, wherein the plurality of fibers comprises at least one of carbon fibers, graphite fibers, or aramid fibers.
7. The insulation material of claim 1, wherein the partially cured preceramic polymer coating comprises a thickness less than a mean diameter of the plurality of fibers.
8. The insulation material of claim 1, wherein the plurality of fibers comprises a sheet of connected fibers.
9. A method of forming an insulation material, comprising:  
applying a preceramic polymer to a plurality of fibers, wherein the preceramic polymer comprises a material selected from the group consisting of a polycarbosilane, a polysilazane, a polysiloxane, and combinations thereof;  
heating the preceramic polymer to form a partially cured preceramic polymer coating on the plurality of fibers;  
disposing the plurality of fibers in a polymeric material;  
and  
curing the polymeric material to form a cross-linked polymeric matrix without fully curing the partially cured preceramic polymer.
10. The method of claim 9, wherein curing the polymeric material comprises exposing the polymeric material to a temperature sufficient to crosslink the polymeric material without sintering the preceramic polymer.
11. The method of claim 9, wherein disposing the plurality of fibers in a polymeric material comprises encapsulating the plurality of fibers in the polymeric material.

## 16

12. The method of claim 9, wherein heating the preceramic polymer to form a partially cured preceramic polymer coating on the plurality of fibers comprises heating the preceramic polymer to a temperature from about 100° C. to about 300° C.

13. The method of claim 9, wherein curing the polymeric material comprises maintaining the polymeric material at a temperature from about 100° C. to about 300° C.

14. A method of insulating an article, comprising:

coating a plurality of fibers with a partially cured preceramic polymer formulated to form a ceramic upon exposure to a temperature of at least about 850° C., wherein a preceramic polymer of the partially cured preceramic polymer comprises a material selected from the group consisting of a polycarbosilane, a polysilazane, a polysiloxane, and combinations thereof;

dispersing the plurality of coated fibers in an insulation precursor;

curing the insulation precursor to form an insulation material comprising a cross-linked polymeric matrix in which the plurality of coated fibers is dispersed without sintering the partially cured preceramic polymer;

applying the insulation material to at least one surface of an article; and

providing an energetic material over the insulation material.

15. An article, comprising:

an insulation material over at least one surface of an article, the insulation material comprising:

a plurality of fibers coated with a partially cured preceramic polymer, wherein a preceramic polymer of the partially cured preceramic polymer comprises a material selected from the group consisting of a polycarbosilane, a polysilazane, a polysiloxane, and combinations thereof; and

the plurality of coated fibers dispersed in a cross-linked polymeric matrix.

16. The article of claim 15, wherein the insulation material at least partially defines at least one interior volume, the article further comprising an energetic composition disposed within the at least one interior volume at least partially defined by the insulation material.

17. The article of claim 16, wherein the energetic composition is selected from the group consisting of a propellant composition, a gas generator composition, a smokeless gun powder composition, a munitions composition, and an explosive composition.

18. The article of claim 15, wherein the article comprises a rocket motor, a rocket motor nozzle, a gas generating device, ordnance, or munitions.

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