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(54) Title: THERMITE IGNITION AND RUSTY IRON REGENERATION BY LOCALIZED MICROWAVES

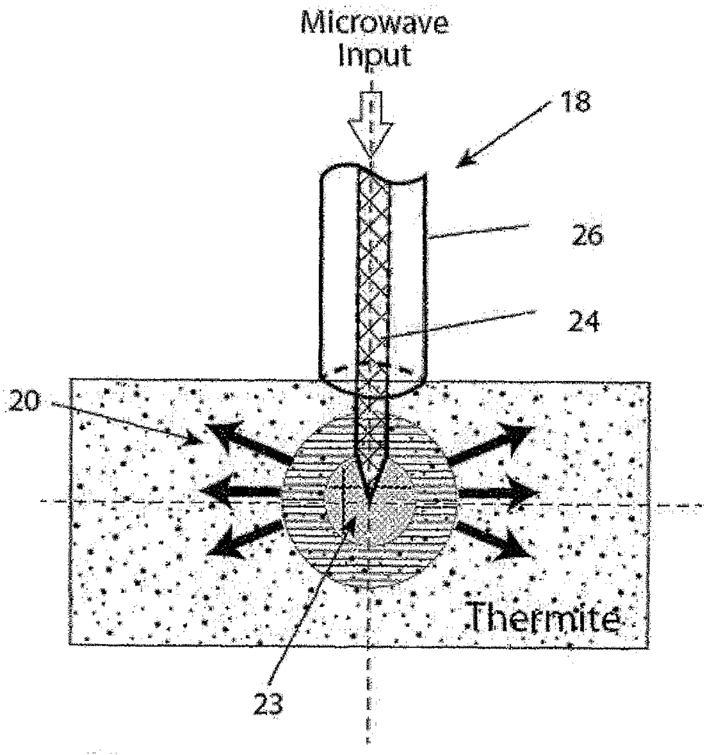

FIG. 2

(57) **Abstract**: A method and corresponding devices employ a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction. Microwave radiation is applied to the mixture so as to generate a localized hot spot in the mixture, thereby initiating the exothermic chemical reaction. The use of localized microwave radiation facilitates low power and portable implementations. Devices and techniques for cutting, drilling, welding, material synthesis, generating thrust, and mechanical power and motion are also disclosed.

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APPLICATION FOR PATENT

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FIELD AND BACKGROUND OF THE INVENTION

Thermite is a general term for exothermic reactions between metals and oxidizers. The latter is typically a metal oxide, which utilizes the reduction of the metallic oxide with the metallic element to exhaust a significant amount of heat. One of the most common mixtures of thermite powder contains hematite and aluminum, which function as the metal-oxidizer and the metallic element, respectively. The final products generated are pure iron, alumina, and heat energy. The corresponding chemical formula that describes this reaction is

$$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3 + Q_{heat} \quad , \tag{1}$$

where the heat energy released Q_{heat} is 3.947 kJ/g in this reaction (for the sake of comparison, the heat released in trinitrotoluene (TNT) explosion is 4.247 kJ/g theoretically). Furthermore, the thermite adiabatic flame temperature in the example above may reach 4,382 K (reduced though to 3,135 K if including the losses due to the phase change during the process). This combustion temperature is found to be much hotter than hydrocarbon-based fuel flame such as Benzene, which has a flame temperature of 2,342 K. Moreover, the thermite combustion temperature is higher than the melting temperatures of its two initial components in separate (1,838 K for iron rust and 933 K for aluminum). Consequently, the combustion of a thermite mixture can be a self propagating process. Due to the intense blackbody radiation emitted by the high-temperature thermite combustion, the thermite reaction can be detected by a radiation detector even at microwave frequencies.

The bi-molecular thermite reaction rate is limited by diffusion due to the mass transfer mechanism between the metal and the oxidizer particles. Hence this reaction is significantly slow compared to the monomolecular based explosives such as TNT. Thermite combustion rate was studied and simulated, and was found to be in the range of ~0.02-0.05 m/s. This speed is extremely slow compared to the TNT detonation velocity of 6,850 m/s. The thermite combustion rate is highly dependent on the contact surface area of the metal and the oxidizer, as determined by the powder particle size (smaller particles cause faster combustion rates). Thus, nano-composite thermite powders benefit a significant increase in the combustion rate value. In a thermite mixture of Al-MoO_3 for instance the combustion speed may reach 600-1,000 m/s. In addition, the ignition time delay can be shortened by two orders of magnitude compared to the micron-sized thermite composites. Except that the inhalation of any thin powder should be avoided, the ferro-thermite components are relatively non toxic, which is not the case for TNT explosives or nitroglycerin.

The gas phase is absent in the thermite reaction, as can be seen by its chemical formula in Eq. (1), hence the direct blast pressure formed is significantly reduced compared to common explosives. TNT for example, releases large amount of gas during a complete balanced decomposition, even though additional oxygen is required as inferred from the following formula

$$2C_7H_5N_3O_6 \rightarrow 14CO_2 + 5H_2O + 3N_2 - 21O \qquad (2)$$

The pressure formed can be calculated by the ideal gas formula modified for high pressure values with the co-volume factor α

$$P_e = \frac{nRT_e}{V(1-\alpha)} \qquad (3)$$

where V is the volume of the closed test cell, n is the produced number of gas moles, T_e is the explosion temperature, and R is the molar gas constant. When oxygen is lack and the TNT decomposition is not balanced, the generated gas is reduced and it contains different kinds of molecules such as carbon monoxide and hydrogen according to Kistiakowsky-Wilson rules. While the oxygen has to come from an external source in TNT and in other conventional hydrocarbon based fuels, it is an inherent component in the thermite mixture, and it is sufficient for a balanced combustion. As a result, the thermite fuel can be incinerated at oxygen-free environments, such as underwater operations. In addition, thermite as a fuel can be used as a "clean" energy source; due to the lack of carbon molecules it never emits carbon monoxide contamination.

The thermite ignition temperature is higher than 1500°C for the Fe_2O_3-Al thermite mixture. However, for the nanometer-size thermite mixtures, the ignition temperature, as one of their superior properties, can reach as low as 410°C as super-thermite. This temperature is derived from the high melting temperature of the ingredients which is extremely high as opposed to TNT which requires a temperature of only 300°C to be ignited. This fact makes the thermite mixture more stable, but also harder to ignite, thus a suitable igniter is required for this kind of metal fuel. The ignition of the thermite mixture above can be achieved by a laser beam for MoO_3-Al and Fe_2O_3-Al thermite mixture. Microwave ignition has been reported in the literature, but it involved a microwave pulse of high power (>50 kW) and high frequency (75 GHz) from a gyrotron. Other microwave schemes were proposed for heating energetic materials.

Thermite ignition by a conventional flame requires a significant reduction of the ignition temperature, typically by adding oxidizer and binder to the thermite powder. For example the 'Thermate-TH3' mixture, which is used in AN-M14 incendiary hand grenade of the US army, is composed of 29% barium nitrate (BaN2O6), sulfur, and a binder, added to 68.7% of thermite. Furthermore, thermite-based grenades contains a starter mixture composed of 66% potassium nitrate (KNO3) and other materials (for the ignition as enriched oxide source) added to the oxide enriched thermite powder. The starter mixture may contain ultra fine thermite powder which is easier to ignite with a hotwire energized by DC current.

In the absence of an oxidizer in the intermediate starting mixture, it is almost impossible to initiate the thermite combustion in a closed can, even with a Nichrome hotwire energized by electric current (melted at 1,400°C). Hence, calcium peroxide (CaO_2) is added in order to lower the ignition temperature and enable the mixture ignition. Another method to ignite a thermite mixture is by adding barium peroxide (BaO_2) to the thermite and lighten it by a magnesium ribbon. Yet, it is a dangerous process since it is hard to control the magnesium combustion. Alternatively the magnesium can be replaced by potassium permanganate ($KMnO_4$) with glycerin. This kind of salt is used as an oxidizing agent that generates enough heat as required to ignite the thermite when it burns. Due to their unique features, thermite powders are used in explosive charges, in devices used for cutting or penetrating metals, and in air-bag system inflators.

Except for its explosive features, the thermite reaction is used in material processing including metals, ceramics, and composite materials. Due to the thermite high combustion temperature, it is utilized also for welding techniques. Thermite based reactions can be utilized for covering iron alloys by an intermediate pure metal and alumina coating, as the ceramic material created by the thermite combustion (note that a centrifugal thermite process uses this feature for making composite steel pipes by filling them with thermite and ignites it while the pipe is rolling around its symmetrical axis).

There is also a special need to ignite small quantities of pure thermite, which is usually less efficient by conventional ignition techniques because of the relatively large igniter needed (possibly even larger the thermite mixture itself). Small-quantity thermite applications could be useful for example in thermite welding of small parts, or for small-scale material synthesis by the thermite combustion (e.g. for production of alumina and iron as in Eq. (1)).

There are therefore various needs for methods and corresponding devices for employing thermite reactions actuated by localized application of microwaves.

SUMMARY OF THE INVENTION

The present invention is a method and corresponding devices for employing thermite reactions actuated by localized application of microwaves.

According to the teachings of the present invention there is provided, a method comprising the steps of: (a) providing a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction; and (b) applying microwave radiation to the mixture so as to generate a localized hot spot in the mixture, the localized hot spot having at least one dimension smaller than the wavelength of the microwave radiation, thereby initiating the exothermic chemical reaction.

According to an embodiment of the present invention, the exothermic chemical reaction has an ignition temperature in excess of 900 degrees Celsius.

According to an embodiment of the present invention, the exothermic chemical reaction has an ignition temperature in excess of 1400 degrees Celsius.

According to an embodiment of the present invention, the exothermic chemical reaction is a thermite reaction.

According to an embodiment of the present invention, the microwave radiation is generated by a microwave source of power less than 2 kW.

According to an embodiment of the present invention, the microwave radiation is generated by a microwave source of power less than 200 W.

According to an embodiment of the present invention, the microwave radiation is generated by a solid-state microwave source.

According to an embodiment of the present invention, the applying is performed by coupling an evanescent field with the mixture.

According to an embodiment of the present invention, the applying is performed using an open ended waveguide as an applicator.

According to an embodiment of the present invention, the applying is performed using a waveguide terminating at one or more slot as an antenna.

According to an embodiment of the present invention, the mixture is deployed so as to achieve cutting, drilling, or welding of adjacent materials when initiated.

According to an embodiment of the present invention, the applying is performed in an oxygen free environment such as underwater.

According to an embodiment of the present invention, the mixture includes rust formed on the surface of an iron-based metal object and a reactive metal such that the chemical reaction is effective to convert the rust to iron.

According to an embodiment of the present invention, the mixture is dynamically added to a reaction region within which the microwave radiation is applied to the mixture during application of the microwave radiation to the mixture.

According to an embodiment of the present invention, the mixture includes at least one gas-generating reagent.

According to an embodiment of the present invention, the applying microwave radiation is performed within a rocket motor arrangement to generate thrust.

According to an embodiment of the present invention, gas pressure is converted to mechanical motion so as to serve as an engine powering a mechanical device.

According to an embodiment of the present invention, the mixture is chosen so that the exothermic reaction performs a self-propagating high-temperature synthesis (SHS) of a porous material.

There is also provided according to the teachings of an embodiment of the present invention, a method comprising the steps of: (a) providing a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction; and (b) applying microwave radiation to the mixture so as to generate heat within the mixture, thereby initiating the exothermic chemical reaction, wherein said microwave radiation is applied in a manner so as to satisfy at least one of the conditions: (i) a hot spot is generated in the mixture, said hot spot having at least one dimension smaller than the wavelength of the microwave radiation; (ii) heat is generated in a region having at least one dimension smaller than the wavelength of the microwave radiation; (iii) a hot spot is generated in a region smaller than a volume of the mixture.

There is also provided according to the teachings of an embodiment of the present invention, a method comprising the steps of: (a) providing a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction; and (b) applying electromagnetic radiation having a at one or more frequency in the range of 1 MHz to 1 THz to the mixture so as to generate heat within generate a localized hot spot in the mixture, said localized hot spot having at least one dimension smaller than the wavelength of the electromagnetic radiation, thereby initiating the exothermic chemical reaction, said electromagnetic radiation is applied in a manner so as to satisfy at least one of the conditions: (i) a hot spot is generated in the mixture, said hot spot having at least one dimension smaller than the wavelength of the electromagnetic radiation; (ii) heat is generated in a region having at least one dimension smaller than the wavelength of the electromagnetic radiation; (iii) a hot spot is generated in a region smaller than a volume of the mixture.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1 is an optional block diagram of an embodiment of the present invention for initiating thermite reactions by localized application of microwave radiation;

FIG. 2 is a schematic representation of a suggested but non-limiting principle of operation of thermite ignition by localized application of microwave radiation according to an aspect of the present invention, illustrated with a coaxial microwave applicator;

FIGS. 3A and 3B are a schematic isometric and side view, respectively, of a tapered near-field microwave applicator for use in an embodiment of the present invention;

FIG. 4 is a schematic illustration of a slot-type near-field microwave applicator for use in an embodiment of the present invention;

FIG. 5 is a schematic illustration of a strip-line-type near-field microwave applicator for use in an embodiment of the present invention;

FIG. 6A is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention;

FIG. 6B is a schematic cross-sectional view of the device of FIG. 6A while in use;

FIG. 7A is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention serving as a torch;

FIG. 7B is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention serving as a torch;

FIG. 8 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention serving as a cutting tool;

FIG. 9 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention serving as a cutting tool;

FIG. 10 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention serving as a cutting tool;

FIG. 11 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention performing rust conversion;

FIG. 12 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention performing rust conversion;

FIG. 13 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention performing material synthesis in batch processing;

FIG. 14 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention performing material synthesis in continuous processing;

FIG. 15 is a schematic isometric view of a device for employing a thermite reaction actuated by localized application of microwaves according to an embodiment of the present invention operating as a rocket engine; and

FIG. 16 is a schematic representation showing the ignition of a larger volume of thermite by an arrangement of several microwave applicators in an array radiating simultaneously, or sequentially, into the volume to ignite it in several places or in a joint focal point.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a method and corresponding devices for employing thermite reactions actuated by localized application of microwaves.

The principles and operation of methods and devices according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, Figure 1 illustrates schematically a system, generally designated **10**, according to certain embodiments of the present invention, and suitable for implementing certain methods according to the present invention. Generally speaking, system **10** includes a microwave source **12** that supplies microwave radiation to a waveguide **16** which terminates at an applicator **18**, referred to as a "concentrator", configured for coupling of near-field microwave radiation into a mixture **20** containing at least a metal oxide and a metal which undergo an exothermic chemical reaction. As illustrated schematically in FIG. 2, applicator **18** is configured to localize delivery of the microwave radiation so as to generate a localized hot spot **23** in mixture **20**, the localized hot spot having at least one dimension smaller than a wavelength of the microwave radiation and/or being smaller than the volume of the mixture, thereby initiating the exothermic chemical reaction.

Thus, the present invention provides a novel ignition method and corresponding igniter for thermite mixtures without requiring intermediate chemical additives. Localized microwave energy has been shown to generate sufficient heat to ignite thermite. Instead of lowering the ignition temperature of the thermite, the hotspot induced intentionally by a relatively low power microwave applicator with a concentrator generates enough heat-per-volume for thermite ignition.

Since no starter mixture is required in order to achieve ignition of a thermite mixture according to the present invention, the invention provides a viable solution for situations where small quantities of mixture (particularly pure thermite) are to be ignited. Thus, in certain preferred applications, the method of the present invention is used to ignite a quantity of thermite mixture of less than 10 g, and in certain cases, less than 1 g.

On the other hand, the present invention is also scalable for igniting large quantities of thermite mixture. Larger quantities may range from 10 g up to 1000 g, and in certain preferred cases, more than 1 kg. In certain cases, it may be advantageous to employ a penetrating applicator for delivering the microwave radiation to a location within the volume of the mixture. In other cases, it may be advantageous to employ simultaneous delivery of microwave radiation at several locations, such as will be described below with reference to FIG. 16.

According to another aspect of the invention, the microwave igniter is used for the removal of rust by iron regeneration. This reaction is achieved by local thermite combustion of rust and aluminum powder ignited by the microwave igniter. The regenerated iron and alumina obtained as the final products can be used to coat the originally rusted object. These and other aspects of the present invention will be better understood by reference to the following detailed description and accompanying drawings.

At this stage, it will be helpful to define certain terminology as used herein in the description and claims. The invention is described as relating to ignition of a mixture of a metal oxide and a metal which undergoes an exothermic chemical reaction, and particularly, reactions of this type which have a high ignition temperature. Preferably, the invention is implemented with mixtures that undergo exothermic chemical reactions with ignition temperature in excess of 900 degrees Celsius, and more preferably in excess of 1400 degrees Celsius. In certain particularly preferred but non-limiting implementations, the exothermic chemical reaction is a thermite reaction, namely, a two-component mixture of a metal oxide and a metal, and in certain particularly preferred options, a pure thermite mixture without any additives.

The use of pure thermite mixture which is facilitated by the present invention makes available a range of additional applications which would either otherwise not be feasible due to the need for expensive and bulky high-energy equipment to initiate the reaction according to conventional techniques.

The general term "microwave" is used herein in the description and claims, except where otherwise qualified, to refer broadly to the broadest range of electromagnetic radiation normally referred to as "microwave", and its bordering regions of the spectrum which, for the purpose of the present invention, may be used to achieve similar effects. In quantitative terms, the present invention is applicable for electromagnetic waves in frequencies between ~1 MHz to ~1 THz, which overlaps frequencies typically referred to as radio frequencies (RF) and millimeter waves, respectively. Certain particularly preferred implementations employ microwave radiation at frequencies in the range of 300 MHz to 300 GHz (wavelengths of 1 meter to 1 millimeter). In some cases, where the wavelength is longer than the dimensions of the volume of the mixture to be ignited, the entire volume of mixture may be considered the "hot spot" according to the present invention, still being a "spot" in the sense that the radiation is localized into a volume having at least one dimension less than the wavelength. In cases of very small wavelengths, the hot spot may not always remain localized within less than a wavelength, but in such cases will be small compared to the volume of the mixture. Thus, preferred applications of the present invention typically satisfy at least one of the conditions:

(i) a hot spot is generated in the mixture, the hot spot having at least one dimension smaller than the wavelength of the radiation;

(ii) heat is generated in a region having at least one dimension smaller than the wavelength of the radiation;

(iii) a hot spot is generated in a region smaller than a volume of the mixture.

In this context, the term "hot spot" is used to refer to a localized region or volume within a larger volume within which material is heated significantly above the temperature of the surrounding material. The size of the hot spot may conveniently be defined by the full width at half maximum (FWHM), i.e., the dimensions of the region for which the temperature is above 50% of the temperature difference between the peak temperature and the surrounding mixture.

According to certain preferred implementations of the present invention, the microwave source is a relatively low power source, typically generating no more than 2 kW, and in certain particularly preferred implementations, no more than 200 W. Also according to certain preferred embodiments, the frequency used is also preferably a relatively low frequency in the microwave range (typically 2.45 GHz). Despite this low power and low frequency, as a result of the concentration of the radiation into a small volume, sufficient localized heating is achieved to generate a localized hot spot at high enough temperature to ignite the reaction. The low power requirements enable the use of a solid-state microwave source, thereby making it feasible to implement the system as a compact and light-weight portable device.

It should be appreciated, however, that the present invention is not limited to the aforementioned low-power implementations. Other implementations may, for example, apply power above ~1 kW, either by a vacuum tube or by employing an array of lower power radiating elements. Furthermore, the operating frequency may be any frequency in the microwave range as defined above.

As shown in FIG. 1, microwave source **12** is preferably protected by an isolator **14** (optional), which is a standard off-the-shelf component preventing reflected radiation from damaging the microwave source. Adjustable matching components **22** (optional) may be used to optimize energy delivery to the mixture **20** via applicator **18**.

A wide range of structures may be used to implement applicator **18** of the present invention. Applicator **18** may be implemented either as an antenna located adjacent to, or immersed in, mixture **20**, or may be implemented employing coupling of an evanescent field at the termination of a non-radiating waveguide with the mixture.

By way of a first non-limiting example, FIG. 2 illustrates an implementation of applicator **18** as a coaxial structure including a central conductor **24** extending within an outer conductive sheath **26**. Central conductor **24** extends beyond the end of conductive sheath **26** and is in close proximity to, or more preferably immersed in, mixture **20**. Optionally, as illustrated below in FIG. 6A, part or all of the extending portion of central conductor **24** may be protected by a ceramic layer, provided for example as ceramic beads **36**. It should be note that, in some cases, the open end of a coaxial waveguide without projection of the central conductor, or the end of a circular waveguide above cutoff may also be effective as an applicator when brought into close proximity or contact with mixture **20**.

A further non-limiting example of applicator **18** is illustrated in FIGS. 3A and 3B which show an implementation with a tapered waveguide **30**.

A further non-limiting example of applicator **18** is illustrated in FIG. 4 which shows an implementation using a waveguide terminating at one or more slot **32** as an antenna.

A further non-limiting example of applicator **18** is illustrated in FIG. 5 which shows an implementation using an open ended waveguide, in this case with a protruding central stripline conductor **34**, as an applicator.

Embodiments of the present invention may be implemented in a range of different configurations to provide a range of different types of functionality, as will now be illustrated with reference to a number of non-limiting examples portrayed in FIGS. 6A-15.

Referring to FIGS. 6A and 6B, these show a simple arrangement in which mixture **20** is included within a reaction chamber **40** with an opening **42** formed in its base through which applicator **18** is inserted. The mixture is ignited locally at hot-spot **23** adjacent to the end of the applicator, resulting in self-ignition of the entire contents of the reaction chamber and ejecting a flame in region **44**.

FIGS. 7A and 7B illustrate two non-limiting examples of a thermite-based blow-torch implementation according to the present invention in which mixture **20** is dynamically added to a reaction region within which the microwave radiation is applied to the mixture, thereby providing an ongoing source of intense heat for a variety of applications. In the example of FIG. 7A, a microwave input port **46** (typically present in all embodiments of the invention, but not separately labeled) feeds the microwave signal into coaxial waveguide **48**. An external thermite source **50** is fed by a flow of air pressure **52** or by some other feed arrangement (not shown) through a metal pipe **54** into coaxial waveguide **48**. Pipe **54** is configured to be in microwave cutoff, so the microwave energy cannot propagate through it. A thin ceramic disc **56** blocks thermite mixture from moving up the waveguide, but allows the microwave radiation to pass through it. The thermite powder **20** passes through the hollow coaxial waveguide **48** towards a nozzle **58**. The high microwave power density in this vicinity of the tip **60** of the central conductor ignites the mixture, and consequently a flame **62** is ejected from nozzle **58**.

FIG. 7B is conceptually similar to FIG. 7A, with equivalent elements labeled similarly. In this case, pipe **54** connects directly to the inner channel of a hollow section of the central conductor **64** of the coaxial waveguide **48**. Hot-spot ignition occurs at region **60**, just beyond the end of hollow central conductor **64**, as described above.

Depending upon the density of the thermite mixture flow, the reaction may or may not be self-propagating. In both torch implementations, switching off of the torch is typically achieved by interrupting both the flow of mixture and the microwave delivery.

Turning now to FIGS. 8-10, these illustrate a number of non-limiting but preferred examples of implementations of the present invention useful as cutting tools for cutting material.

The example of FIG. 8 is based on a thermite torch **68**, which may be implemented according to any of FIGS. 6A, 7A or 7B. Torch **68** has a microwave input port **46**, a source of thermite **50** (unless pre-loaded according to FIG. 6A), and generates an output flame **62** towards the body **70** to be cut or otherwise processed, for example, forming a cut **72**.

According to preferred but non-limiting option, flame **62** can be collimated by use of a suitable nozzle shape (not shown). Additionally, or alternatively, for magnetic thermite powder, such as $Fe3O4$-Al, the collimation can be done by externally induced magnetic fields. For example, by attaching a permanent magnet to the metallic substrate it can be magnetized. Consequently the flame made of hot magnetic particles can be collimated to the metal substrate by the induced magnetic field. Alternately, the collimation can be done by a coil that surrounds the flame so it induces an axial magnetic field.

Turning now to FIG. 9, this shows an alternative cutting technique in which thermite mixture **20** is applied to the surface of the body to be cut or otherwise processed, and is then ignited by the system **10** of FIG. 1 using any suitable applicator, such as those discussed above. Thus, microwave radiation delivered to input port **46** along waveguide **16** via applicator **18** ignites mixture **20** at a hotspot generated in the interaction region **60**, and results in cutting or melting of body **70** at region **72**.

FIG. 10 shows an arrangement essentially similar to FIG. 9, and similarly labeled, but in which the thermite mixture is initially at least partially located within a preformed notch **74** formed in the body.

These devices and techniques described here may also be used for drilling holes, or for welding together two initially separate bodies.

Turning now to FIGS. 11 and 12, the ability to ignite a pure thermite mixture conveniently in situ facilitates another particularly preferred aspect of the present invention, namely, a rust conversion technique in which iron can be regenerated from a layer of rust through a thermite reaction which preferably simultaneously generates a protective layer. As illustrated in FIG. 11, a layer of thermite mixture including the oxide of the substrate metal and an additional metal is applied to the substrate metal which has an oxide (rust) outer layer **76**. The mixture is ignited using a device such as was described in FIG. 9. After the thermite is ignited, the oxide layer is converted to the final products of the thermite reaction. For example, thermite made of rust (Fe_2O_3) and aluminum (Al) that covers an iron or steel body with a rusty layer, converts the outer layer to iron and alumina.

FIG. 12 illustrates a system and technique similar to that of FIG. 11, but in which an entire surface is treated by covering in a layer of the thermite mixture **20** and then moving the igniter device progressively across the region (represented by arrow **78**) to ensure ignition of the thermite layer across the entire surface. The resulted layer of regenerated iron and alumina is designated **80**.

Turning now to FIGS. 13 and 14, these illustrate processes for production of materials with particular mechanical or chemical properties by self-propagating high-temperature synthesis (SHS) methods. One particularly preferred example is synthesis of porous ferrite. The production process may be either a batch process (FIG. 13) or a continuous process (FIG. 14).

According to the option of FIG. 13, a microwave igniter such as that of FIG. 9 ignites the mixture **20** located in a mold **82**. The mixture may be either pure thermite powder or may contain other materials that interact with the byproducts of the thermite reaction. For example, $3TiO_2+3C+4Al \rightarrow 3TiC+2Al_2O_3$. The reaction between titania (TiO2) and aluminum (Al) is a thermite reaction. The titanium (Ti) reacts with the carbon (C) to produce titanium carbide (TiC). The ignition temperature of this synthesis reaction is 900 C.

FIG. 14 illustrates a continuous flow process in which the microwave igniter ignites the mixture **20** in interaction region **60**. The mixture is placed on a moving conveyer **84** which feeds it under igniter **10**, continuously generating the desired product **86**.

Turning now to FIG. 15, according to a further option, certain embodiments of devices and methods according to the present invention employ mixtures **20** which include at least one gas-generating reagent. The device then becomes a thermite-fueled thrust-generating device, which may be used directly in a rocket engine, or may be employed with a piston arrangement or other device for converting gas pressure to mechanical motion, as a combustion engine, in order to power a mechanical device.

Structurally, FIG. 15 shows schematically a non-limiting example of a thermite-fueled thrust-generating device according to this aspect of the present invention in which a mixer **90** mixes thermite powder mixture **20** with carbon **92**. This mixture is fed into a microwave igniter **94** that utilizes a near-field applicator to ignite the thermite in the mixture by microwave energy. The added carbon is incinerated with the oxygen in the air, or with additional metal oxide that produces extra oxygen, for a balanced chemical reaction. The generated byproducts are emitted outside through a dedicated exhaust **96**. The high pressure gas produced generate the thrust **98**. An external rocket engine or a piston utilizes the emitted thrust to generate mechanical power and motion.

Turning finally to FIG. 16, this illustrates schematically a further set of implementations of the present invention according to which a plurality of microwave applicators **100**, constructed according to any of the above examples, are used as an array **101** or otherwise coordinated to generate one or more ignition hot-spot **102** within a mixture **99**. This approach may be valuable in a wide range of applications including, but not limited to: coordinated heating of a single hot-spot by a plurality of applicators in order to achieve higher overall power, or to reach a greater depth, than would be achieved by a single applicator; simultaneous multi-point ignition of a large quantity, or geometrical extent, of mixture at spaced-apart locations; and sequential ignition of mixture at spaced-apart locations in order to achieve a particular ignition sequence or sequential processing of different regions.

Appendix

The following is an incomplete list of thermite mixtures to which the teachings of the present invention are believed to be applicable:

$2Al+3AgO$, $2Al+3Ag_2O$, $2Al+B_2O_3$, $2Al+Bi_2O_3$, $2Al+3CoO$, $8Al+3Co_3O_4$, $2Al+Cr_2O_3$, $2Al+3CuO$, $2Al+3Cu_2O$, $2Al+Fe_2O_3$, $8Al+3Fe_3O_4$, $2Al+3HgO$, $10Al+3I_2O_5$, $4Al+3MnO_2$, $2Al+MoO_3$, $10Al+3Nb_2O_5$, $2Al+3NiO$, $2Al+Ni_2O_3$, $2Al+3PbO$, $4Al+3PbO_2$, $8Al+3Pb_3O_4$, $2Al+3PdO$, $4Al+3SiO_2$, $2Al+3SnO$, $4Al+3SnO_2$, $10Al+3Ta_2O_5$, $4Al+3TiO_2$, $16Al+3U_3O_8$, $10Al+3V_2O_5$, $4Al+3WO_2$, $2Al+WO_3$,

$2B+Cr_2O_3$, $2B+3CuO$, $2B+Fe_2O_3$, $8B+3Fe_3O_4$, $4B+3MnO_2$, $8B+3Pb_3O_4$,

$3Be+B_2O_3$, $3Be+Cr_2O_3$, $Be+CuO$, $3Be+Fe_2O_3$, $4Be+Fe_3O_4$, $2Be+MnO_2$, $2Be+PbO_2$, $4Be+Pb_3O_4$, $2Be+SiO_2$,

$3Hf+2B_2O_3$, $3Hf+2Cr_2O_3$, $Hf+2CuO$, $3Hf+2Fe_2O_3$, $2Hf+Fe_3O_4$, $Hf+MnO_2$, $2Hf+Pb_3O_4$, $Hf+SiO_2$,

$2La+3AgO$, $2La+3CuO$, $2La+Fe_2O_3$, $2La+3HgO$, $10La+3I_2O_5$, $4La+3MnO_2$, $2La+3PbO$, $4La+3PbO_2$, $8La+3Pb_3O_4$, $2La+3PdO$, $4La+3WO_2$, $2La+WO_3$,

$6Li+B_2O_3$, $6Li+Cr_2O_3$, $2Li+CuO$, $6Li+Fe_2O_3$, $8Li+Fe_3O_4$, $4Li+MnO_2$, $6Li+MoO_3$ $8Li+Pb_3O_4$, $4Li+SiO_2$, $6Li+WO_3$,

$3Mg+B_2O_3$, $3Mg+Cr_2O_3$, $Mg+CuO$, $3Mg+Fe_2O_3$, $4Mg+Fe_3O_4$, $2Mg+MnO_2$, $4Mg+Pb_3O_4$, $2Mg+SiO_2$,

$2Nd+3AgO$, $2Nd+3CuO$, $2Nd+3HgO$, $10Nd+3I_2O_5$, $4Nd+3MnO_2$, $4Nd+3PbO_2$, $8Nd+3Pb_3O_4$, $2Nd+3PdO$, $4Nd+3WO_2$, $2Nd+WO_3$,

$2Ta+5AgO$, $2Ta+5CuO$, $6Ta+5Fe_2O_3$, $2Ta+5HgO$, $2Ta+I_2O_5$, $2Ta+5PbO$, $4Ta+5PbO_2$, $8Ta+5Pb_3O_4$, $2Ta+5PdO$, $4Ta+5WO_2$, $6Ta+5WO_3$,

$3Th+2B_2O_3$, $3Th+2Cr_2O_3$, $Th+2CuO$, $3Th+2Fe_2O_3$, $2Th+Fe_3O_4$, $Th+MnO_2$, $Th+PbO_2$, $2Th+Pb_3O_4$, $Th+SiO_2$,

$3Ti+2B_2O_3$, $3Ti+2Cr_2O_3$, $Ti+2CuO$, $3Ti+2Fe_2O_3$, $Ti+Fe_3O_4$, $Ti+MnO_2$, $2Ti+Pb_3O_4$, $Ti+SiO_2$,

$2Y+3CuO$, $8Y+3Fe_3O_4$, $10Y+3I_2O_5$, $4Y+3MnO_2$, $2Y+MoO_3$, $2Y+Ni_2O_3$, $4Y+3PbO_2$, $2Y+3PdO$, $4Y+3SnO_2$, $10Y+3Ta_2O_5$, $10Y+3V_2O_5$, $2Y+WO_3$,

$3Zr+2B_2O_3$, $3Zr+2Cr_2O_3$, $Zr+2CuO$, $3Zr+2Fe_2O_3$, $2Zr+Fe_3O_4$, $Zr+MnO_2$, $2Zr+Pb_3O_4$, $Zr+SiO_2$,

It will be appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the scope of the present invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A method comprising the steps of:

(a) providing a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction; and

(b) applying microwave radiation to the mixture so as to generate a localized hot spot in the mixture, said localized hot spot having at least one dimension smaller than the wavelength of the microwave radiation, thereby initiating the exothermic chemical reaction.

2. The method of claim 1, wherein said exothermic chemical reaction has an ignition temperature in excess of 900 degrees Celsius.

3. The method of claim 1, wherein said exothermic chemical reaction has an ignition temperature in excess of 1400 degrees Celsius.

4. The method of claim 1, wherein said exothermic chemical reaction is a thermite reaction.

5. The method of claim 1, wherein the microwave radiation is generated by a microwave source of power less than 2 kW.

6. The method of claim 1, wherein the microwave radiation is generated by a microwave source of power less than 200 W.

7. The method of claim 1, wherein the microwave radiation is generated by a solid-state microwave source.

8. The method of claim 1, wherein the microwave radiation is generated at one or more frequency in the range of 300 MHz to 300 GHz.

9. The method of claim 1, wherein a total mass of said mixture is less than 10 g.

10. The method of claim 1, wherein a total mass of said mixture is less than 1 g.

11. The method of claim 1, wherein said applying is performed by coupling an evanescent field with the mixture.

12. The method of claim 1, wherein said applying is performed using an open ended waveguide as an applicator.

13. The method of claim 1, wherein said applying is performed using a waveguide terminating at one or more slot as an antenna.

14. The method of claim 1, wherein the mixture is deployed so as to achieve cutting, drilling, or welding of adjacent materials when initiated.

15. The method of claim 1, wherein said applying is performed underwater or in another oxygen free environment.

16. The method of claim 1, wherein the mixture includes rust formed on the surface of an iron-based metal object and a reactive metal such that the chemical reaction is effective to convert said rust to iron.

17. The method of claim 1, wherein the mixture is dynamically added to a reaction region within which the microwave radiation is applied to the mixture during application of the microwave radiation to the mixture.

18. The method of claim 1, wherein the mixture includes at least one gas-generating reagent.

19. The method of claim 18, wherein said applying microwave radiation is performed within a rocket motor arrangement to generate thrust.

20. The method of claim 18, further comprising converting gas pressure to mechanical motion so as to serve as an engine powering a mechanical device.

21. The method of claim 1, wherein said mixture is chosen so that said exothermic reaction performs a self-propagating high-temperature synthesis (SHS) of a porous material.

22. The method of claim 1, wherein the microwave radiation is provided to the mixture via a plurality of applicators.

23. A method comprising the steps of:

(a) providing a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction; and

(b) applying microwave radiation to the mixture so as to generate heat within the mixture, thereby initiating the exothermic chemical reaction, wherein said microwave radiation is applied in a manner so as to satisfy at least one of the conditions:

(i) a hot spot is generated in the mixture, said hot spot having at least one dimension smaller than the wavelength of the microwave radiation;

(ii) heat is generated in a region having at least one dimension smaller than the wavelength of the microwave radiation;

(iii) a hot spot is generated in a region smaller than a volume of the mixture.

24. A method comprising the steps of:

(a) providing a mixture of at least a metal oxide and a metal which undergoes an exothermic chemical reaction; and

(b) applying electromagnetic radiation at one or more frequency in the range of 1 MHz to 1 THz to the mixture so as to generate heat within the mixture, thereby initiating the exothermic chemical reaction, said electromagnetic radiation is applied in a manner so as to satisfy at least one of the conditions:

(i) a hot spot is generated in the mixture, said hot spot having at least one dimension smaller than the wavelength of the electromagnetic radiation;

(ii) heat is generated in a region having at least one dimension smaller than the wavelength of the electromagnetic radiation;

(iii) a hot spot is generated in a region smaller than a volume of the mixture.

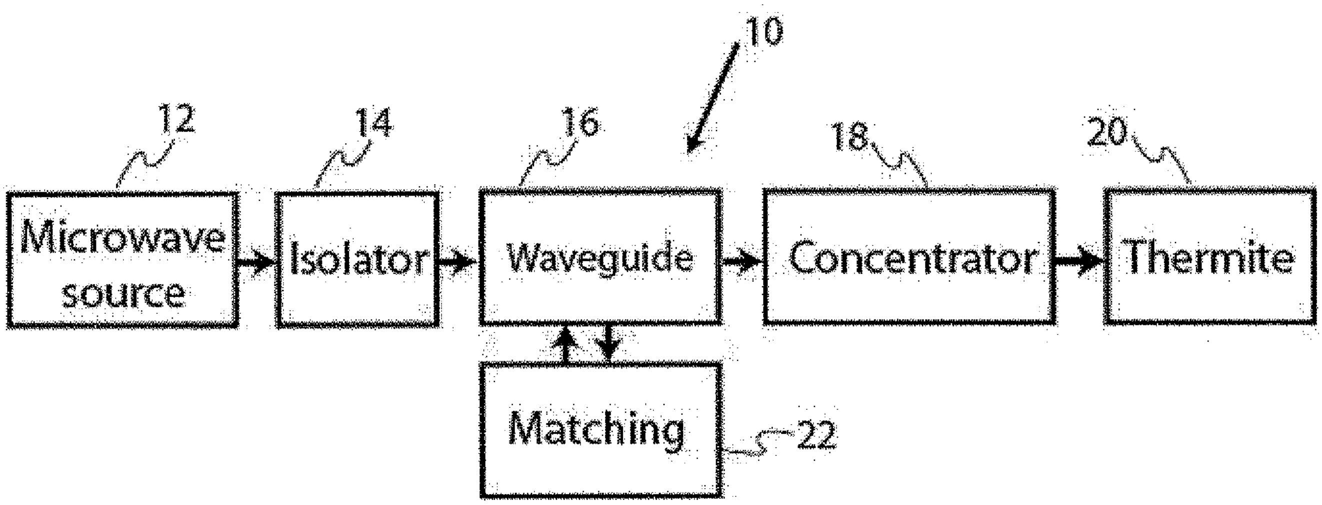

10
12
14
16
18
20
Microwave source
Isolator
Waveguide
Concentrator
Thermite
Matching
22

FIG. 1

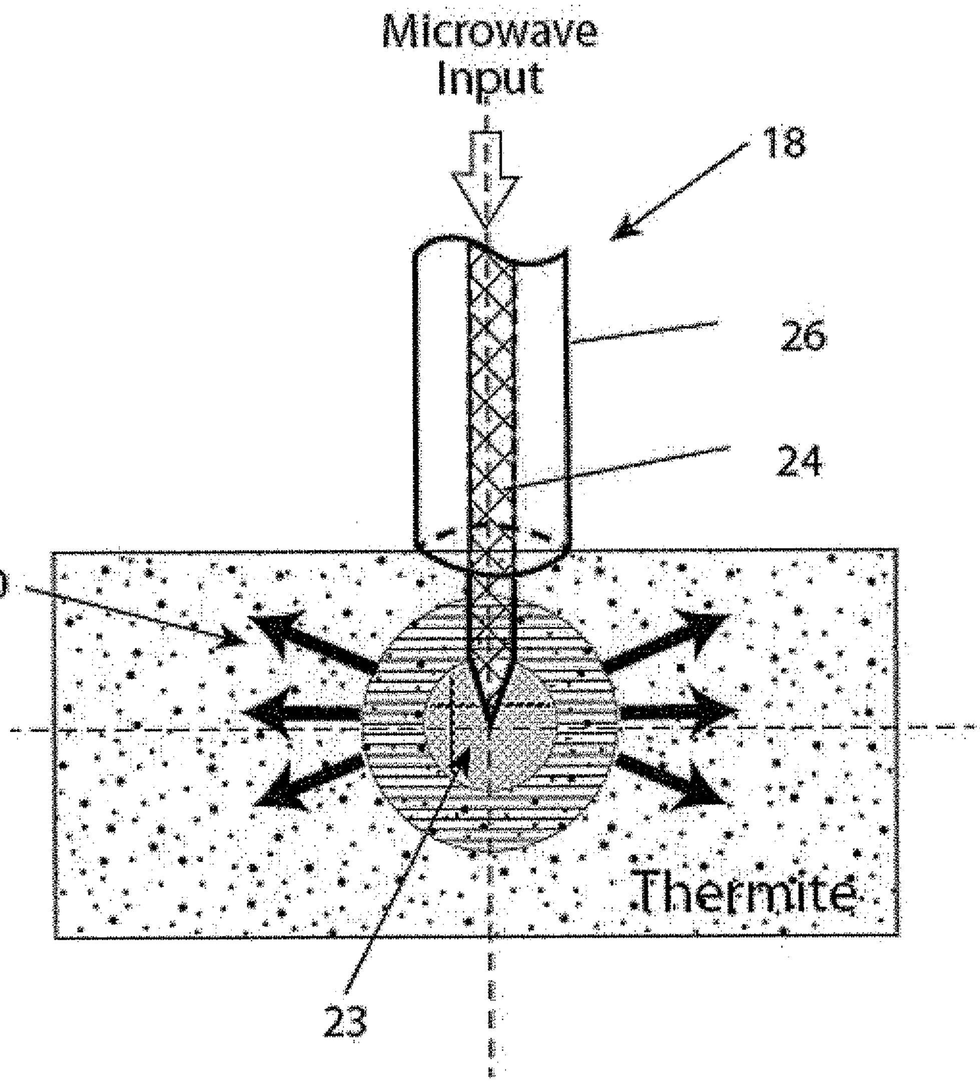
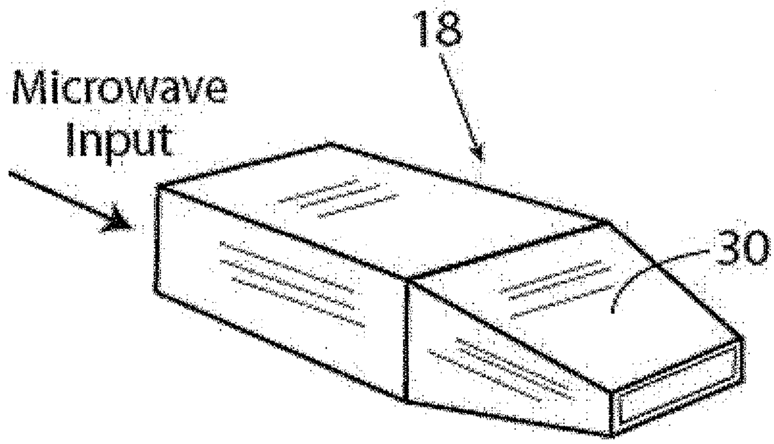


FIG. 2

FIG. 3A



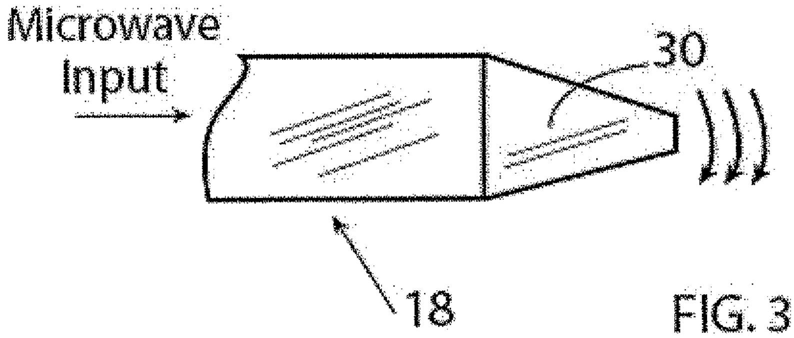


FIG. 3B

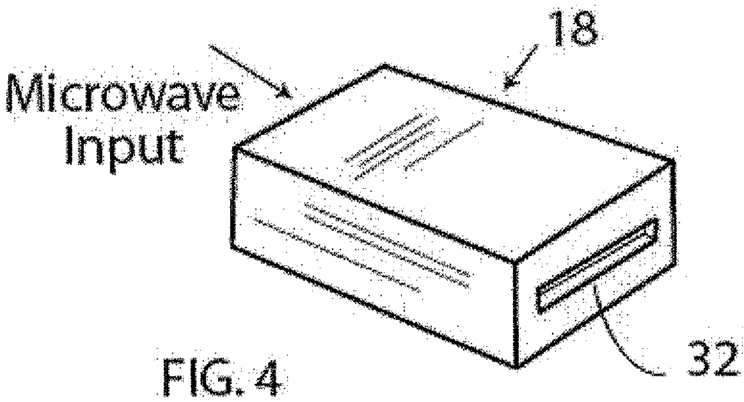


FIG. 4

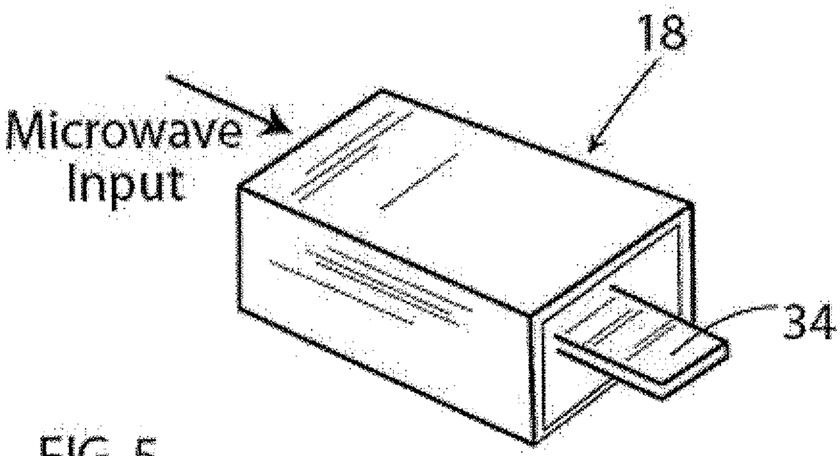


FIG. 5

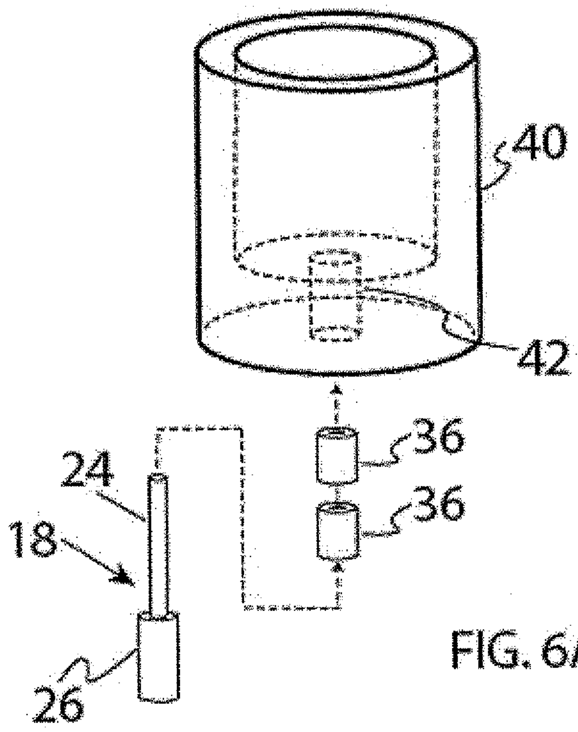


FIG. 6A

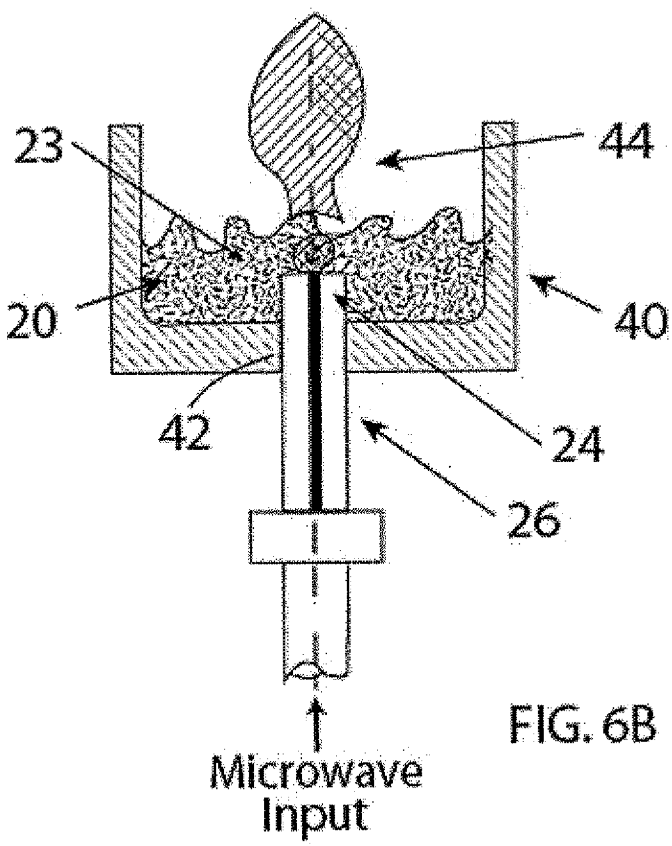


FIG. 6B

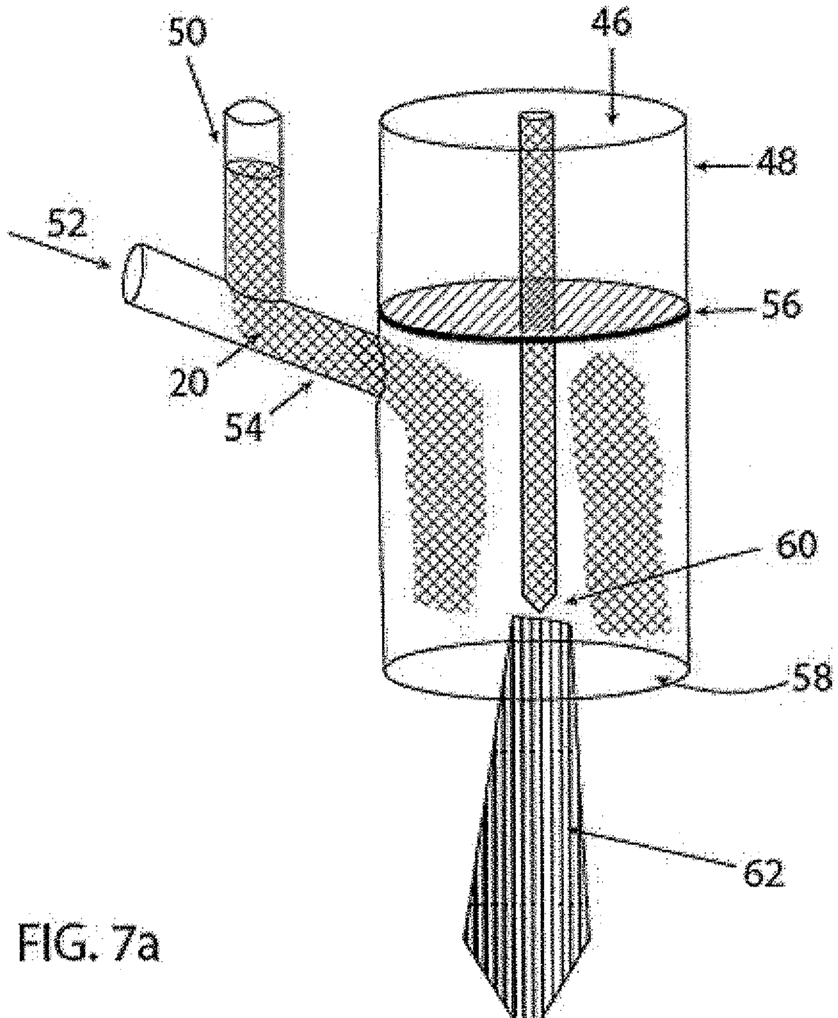


FIG. 7a

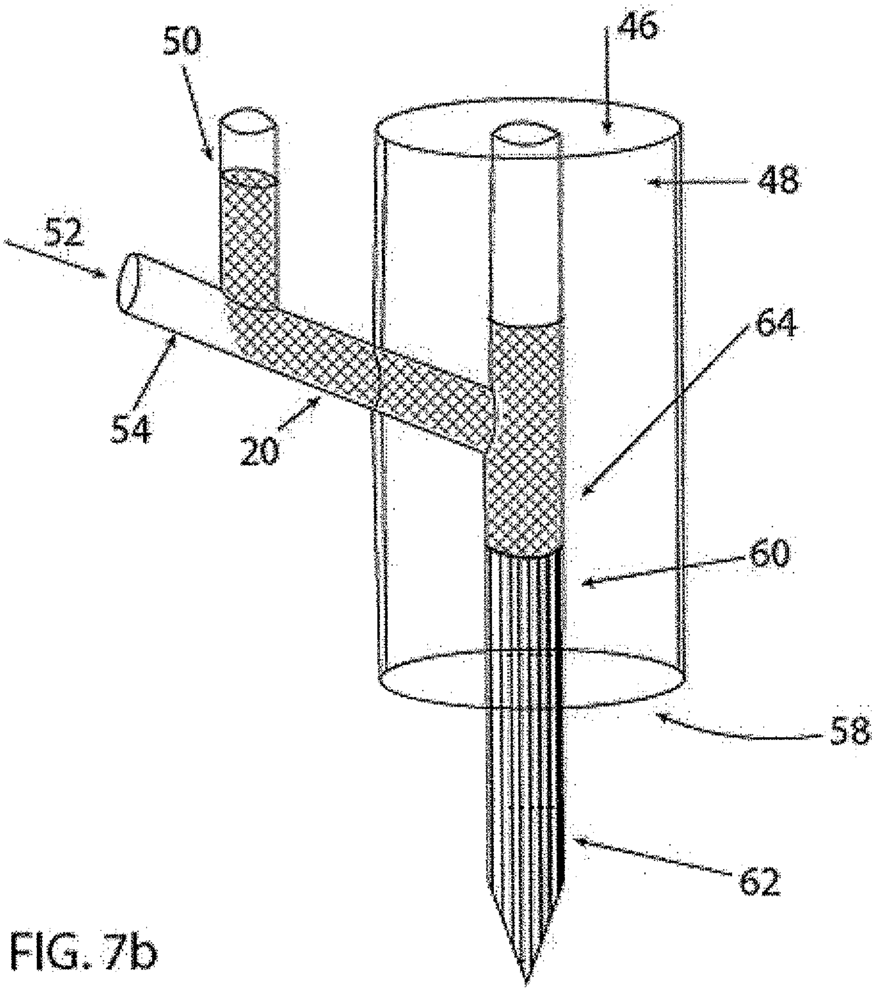


FIG. 7b

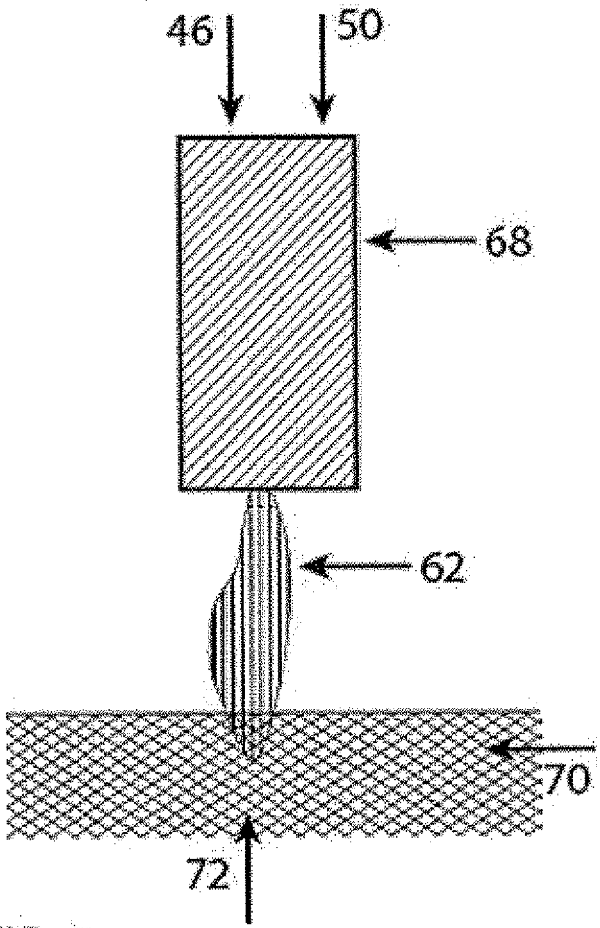


FIG. 8

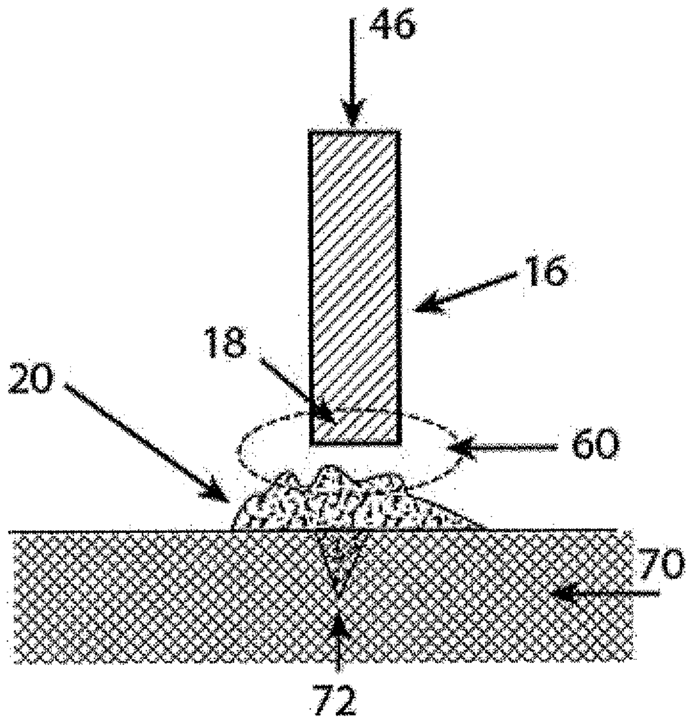


FIG. 9

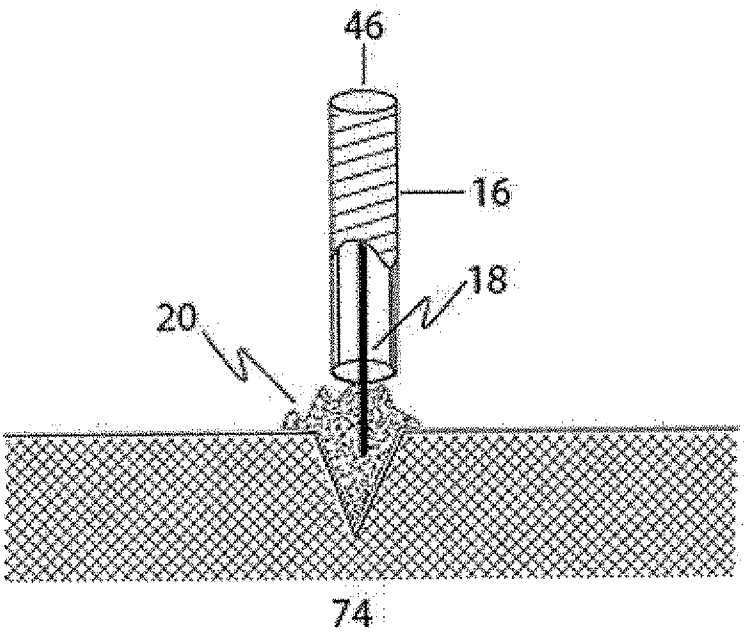


FIG. 10

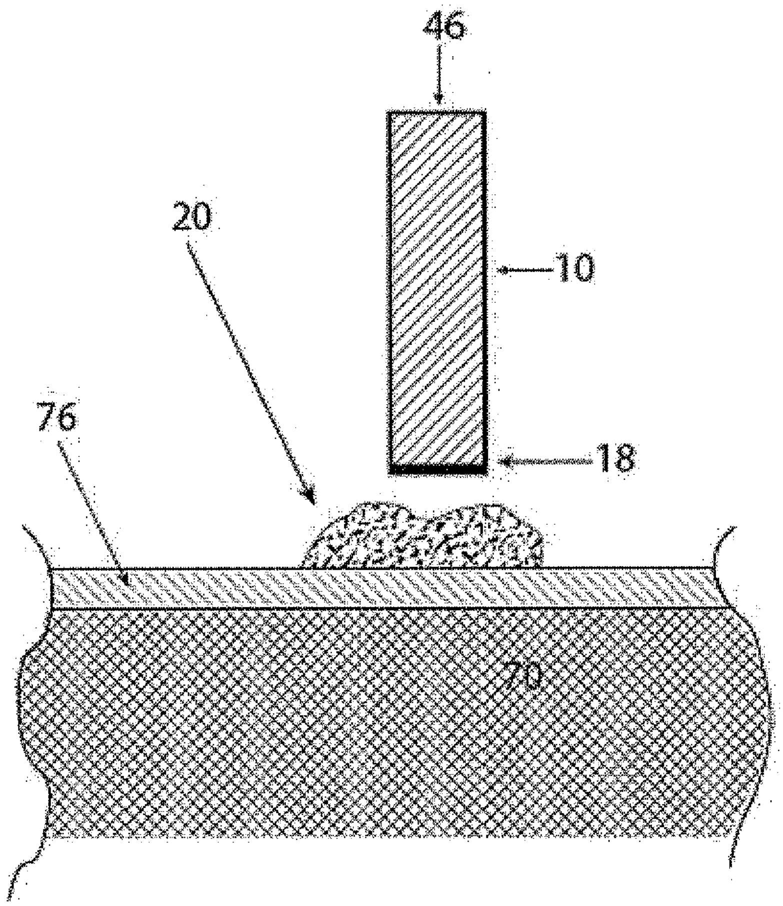


FIG. 11

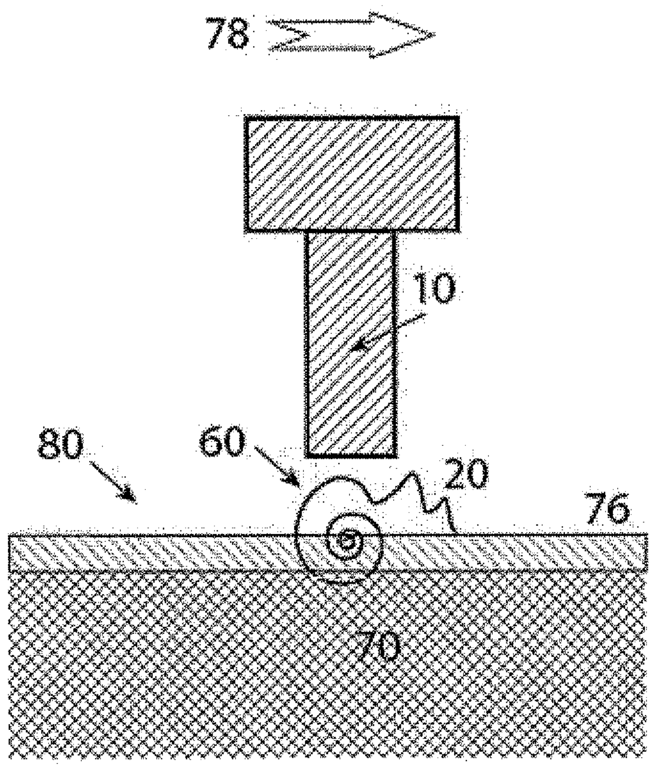


FIG. 12

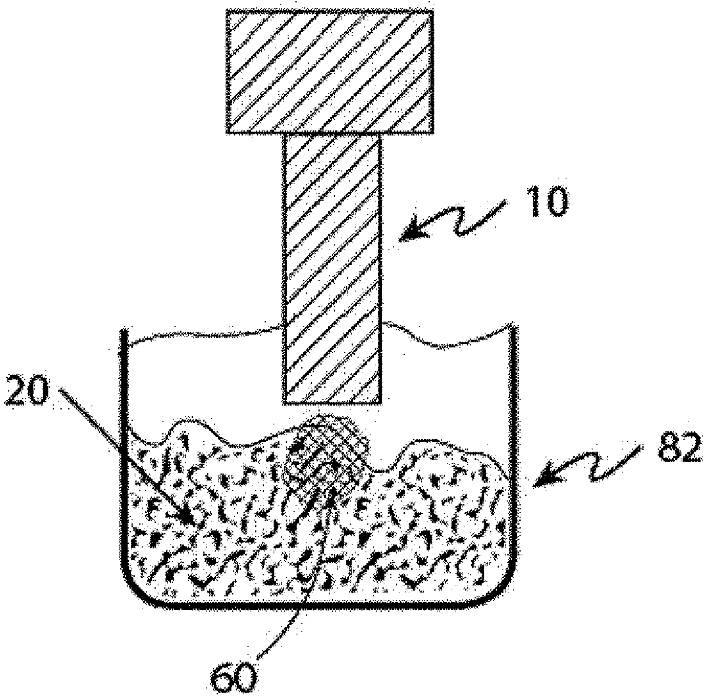


FIG. 13

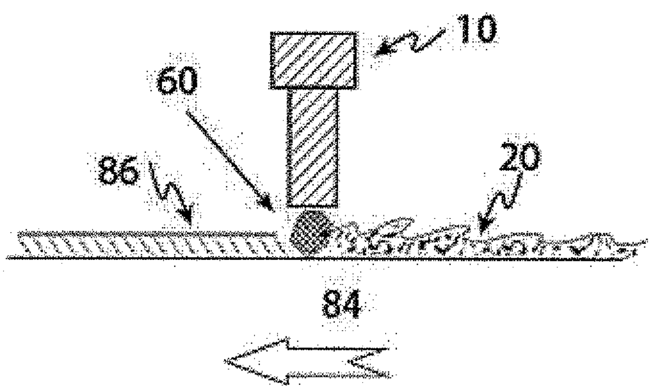


FIG. 14

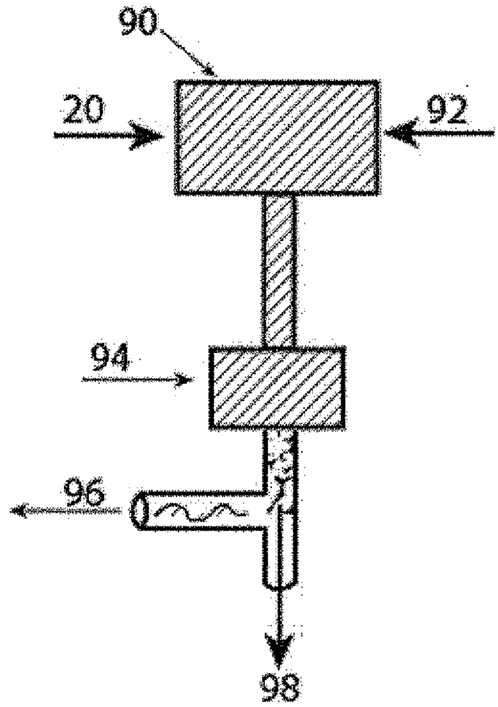
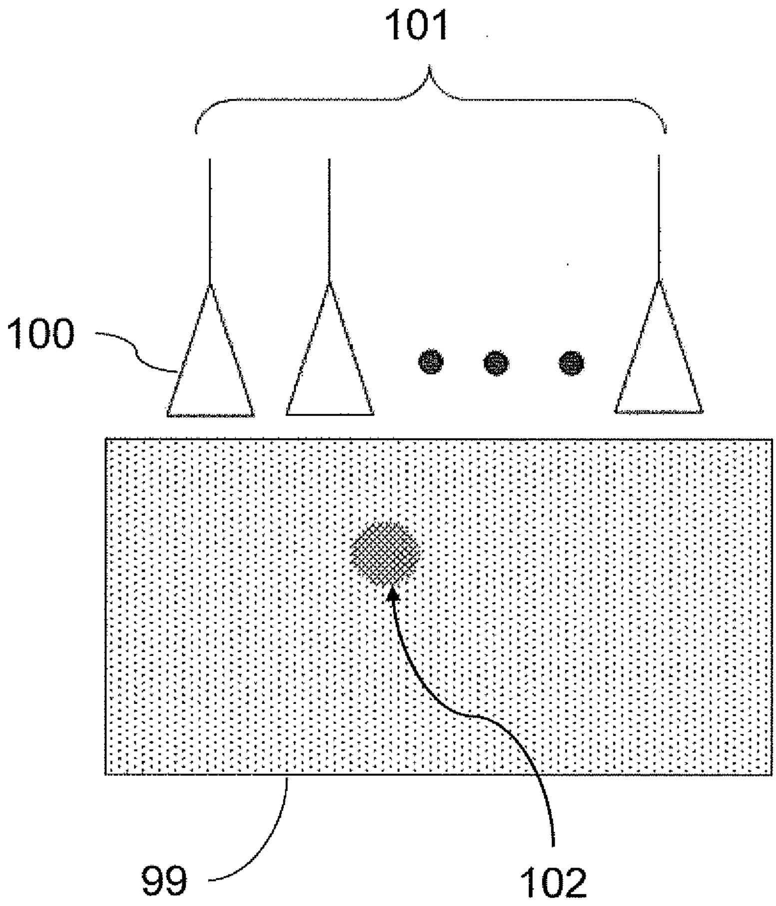


FIG. 15

FIG. 16



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/050964

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J19/12
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22B B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/011083 A1 (PERRY WILLIAM L [US] ET AL) 19 January 2006 (2006-01-19) abstract; figure 1 page 3, paragraph 33 -----	1-24
X	US 2010/068155 A1 (LEI MINGZU [US] ET AL) 18 March 2010 (2010-03-18) abstract page 5, paragraph 62 page 6, paragraph 63 -----	1-24
A	US 6 114 676 A (JERBY ELI [IL] ET AL) 5 September 2000 (2000-09-05) the whole document -----	1-24

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 May 2012	22/05/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Thomasson, Philippe

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2012/050964

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2006011083	A1	19-01-2006	US	2006011083	A1	19-01-2006
			WO	2006085956	A2	17-08-2006
US 2010068155	A1	18-03-2010	NONE			
US 6114676	A	05-09-2000	AT	246869	T	15-08-2003
			AU	1999800	A	07-08-2000
			DE	60004326	D1	11-09-2003
			DE	60004326	T2	01-07-2004
			EP	1147684	A1	24-10-2001
			JP	2002535155	A	22-10-2002
			US	6114676	A	05-09-2000
			WO	0044202	A1	27-07-2000