

Nanothermite Materials and Their Applications: An Overview

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Abstract

This review article described the different synthesis methods of nanothermite material. Nanothermite materials are widely used in defence applications. Firstly reported the different methods of synthesis such as self-assembled, vapour layer and ball milling methods. After that reviewed different applications such as microthruster and micropropulsions.

Introduction

For the better performance in the area of defence every nation need isadvanced technology. The main concern of the today's research is the size of the particle and the functionalization of the materials. During the selection of the materials scientist are more focus on their new synthetic approach, fabrication of the material and their application. In the field of explosives a new class of materials is callednanothermite materials.[1-3] Due to their high surface to volume ratio, and releasing a lot of amount of energy during the combustion, this area is the thrust area of today's defence research.

Initially black powder was used as propulsion materials. However, due to low energy &environmental issues (dirty gas and waste) the development of the next generation propellant was started. Nitrocellulose and nitroguanidine pioneered the next generation propellants. Nitrocellulose is classified as a composition of smokeless powder and propellants are classified in two categories i.e. single base (SB) and double base (DB) propellants.[4] The main composition of the SB is nitrocellulose whereas DB contains nitroglycerine along with nitrocellulose. The other class of the propellant is triple based propellant, in which DB is accompanied by nitroguanidine. Around 1960's composite based propellants were developed, which are made up of the oxidizer (ammonium perchlorate), metallic fuel, organic binder,

plasticizer and other additives. Organic binder binds all the solid ingredients and provides the high energy and mechanical properties. Design of the propellant grain is the close co-ordination with their ballistic properties (burn rate, Cal-Val) and their structural ingredients. Transitional metal oxides (TMO's) are most preferred & widely investigated as burn rate modifier due to their compatibility with most of the constituents in solid rocket propellants. TMO's at nano scale are more efficient as there is substantial increase of propellant deflagration rate and enhancement of the performance parameters such as Cal-Val, and mechanical properties.[5]

Generally iron oxide (Fe_2O_3), chromium oxide (Cr_2O_3 , CrO_3), copper oxide (CuO or Cu_2O), bismuth oxide (Bi_2O_3), Cobalt oxide (CoO), mercuric oxide (HgO), iodine oxide (I_2O_5), manganese oxide (MnO_2), molybdenum oxide (MoO_3), niobium oxide (Nb_2O_5), and nickel oxide (NiO or Ni_2O_3) nanoparticles are used as an oxidizer in thermite materials.[6]

Developing of new methodology towards nano sized metal oxide particles and their applications in the formulation of the thermite materials gaining importance due to obvious reasons. Various methodology should be adopted for the synthesis of nanothermite materials.

Synthesis of nanothermite: Metal oxide when mixed with aluminium metal (fuel) with the aid of binder, it forms the nanothermite material. For synthesis of nanocomposite various methods are used, such as vapour layer deposition, ball milling method, sol-gel method, and self-assembled method.

(a) Vapour layer deposition: In this method various layers of metal and metal oxide are deposited. Once layers were formed, the materials sustain self-propagating exothermic reaction. Metals are deposited on the basis of their reactivity. Reactive multilayer nanofoils used in thermite reactions (Al/CuO) is prepared by vapour layer deposition method [7-9].

Almost all the metals and metal oxides are synthesized by using layer deposition method, which can easily control the thickness of the materials. However, this method is costly and scaling is difficult. Another drawback of this method is bilayer spacing is very small and in few cases bilayers are unstable because of voids generation, which makes it unsuitable for thermite materials.

(b) Ball milling method: Ball milling method is vastly used in thermite materials. ARM (arrested reactive milling method) is a type of ball milling method used in thermites.

ARM: Under milling conditions, mixture of powdered components (micrometer sized), nanostructured energetic composites are prepared. These powdered materials react chemically in milling conditions. Fully dense micron size particles are obtained from nanoenergetic composites. Addition of 2-3 micron size nanoenergetic composites leads to the formation of 100 nm size nanoenergetic composite. ARM method is used for various compositions such as Al/CuO, Al/MoO₃, and Al/ hydrocarbon [10, 11]. This method is cost effective and scalable. Uniformity and the reactivity of the chemical milled nanocomposites was enhanced in the presence of cryogenic conditions (presence of liquid nitrogen).

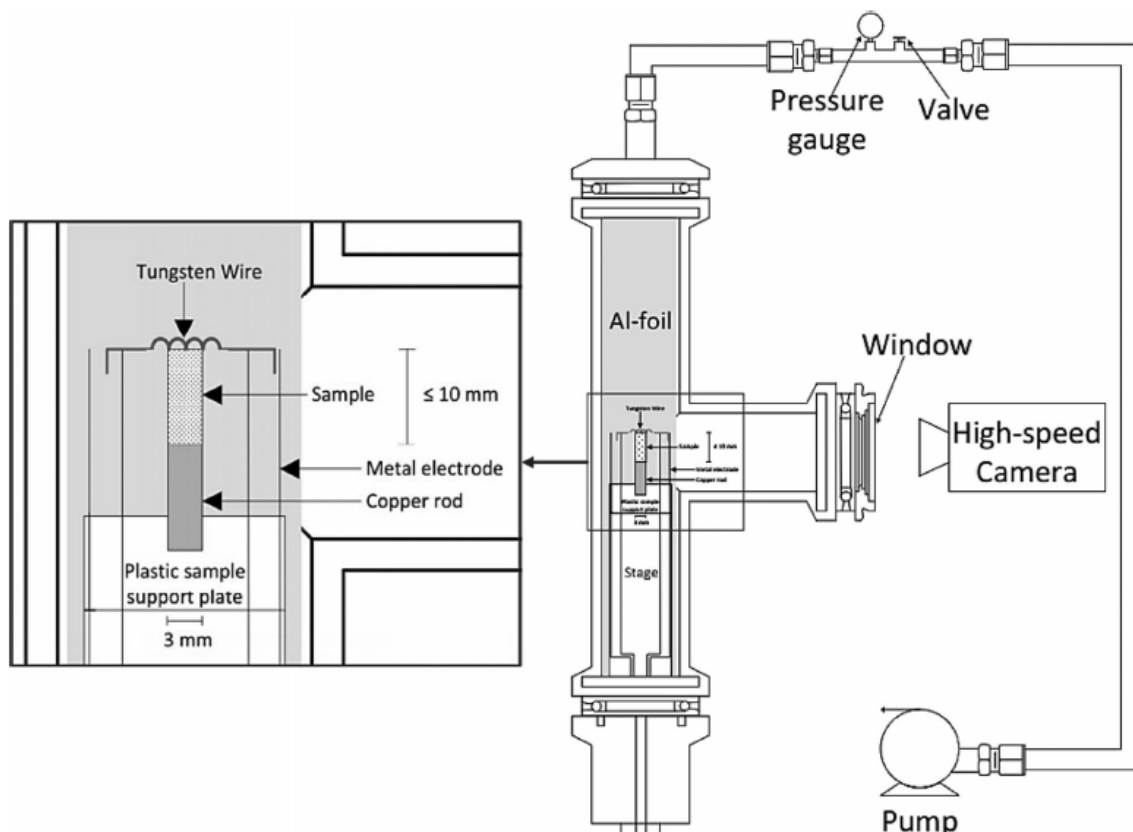


Figure 1: Arrested reactive milling method for thermite preparation

(c) Self-assembly method: This method is vastly used in thermites. This method is responsible for reducing the electrostatic force on the thermite surface. There are two

self- assembly methods a) electrostatic b) self-assembly Based on surface modifier among which electrostatic self-assemble method is widely used.

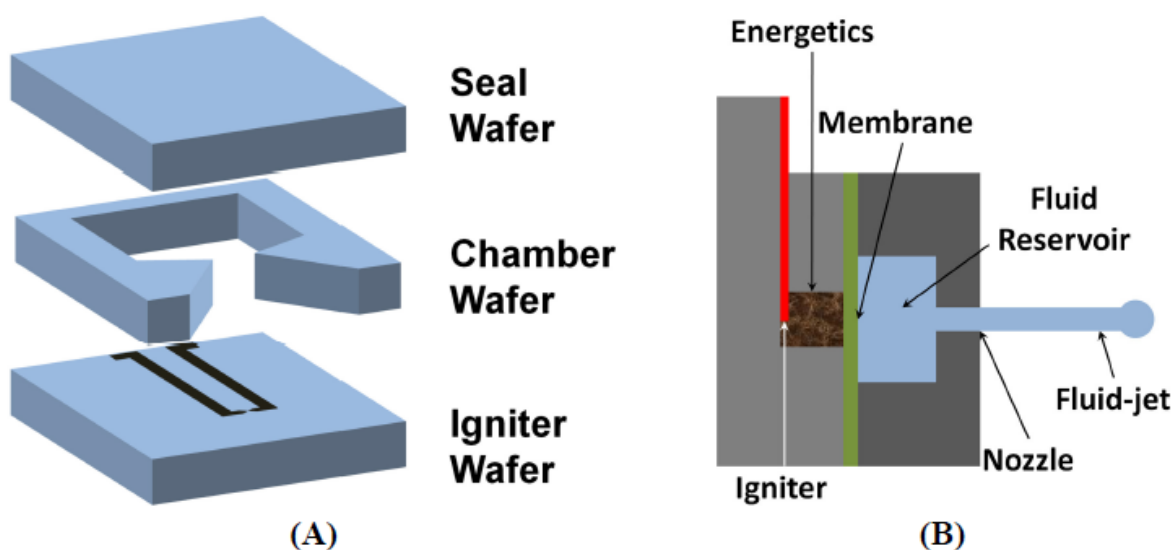
- i. **Electrostatic self-assembly:** In the electrostatic interaction self-assembly approach, the interaction between oxidizer/fuel aerosol particles is enhanced by increasing electrostatic forces on each of the components. In Brownian type of collision, fuel (Al) particles are held together in a linear chain by weak interaction with the oxidizer particles. While, in the case of electrostatic interaction, however, enhanced charged collision yields assembly of a larger number of Al-particles around oxidizer nanoparticles which have better contact between fuel and oxidizer than Brownian assembly [12].
- ii. **Self -assembly based on surface modifier:** For assembly nanoenergetic composites surface modifiers are also used. Poly vinyl pyrrolidone (PVP) is a promising candidate to immobilize nanoparticles because of strong affinity of pyridyl rings with fuel particles. Iron based thermite material, having burn rate and pressuring rate, can self-assemble with polymer matrix. Copper oxide nanoparticles exhibit high burn rate when it is combined with PVP shown in scheme 1 [13,14]. The polymer containing nitro based energetic materials generates more pressure and trigger the explosives.

Scheme 1: Self-assembled nano thermite

Applications of nanothermites

Nanothermite used as an extensively materials in the modern explosives. Nanothermite materials are widely used as a defence material as well as other civilian applications. Here we have reported some applications of nanothermite materials.

Microelectromechanical systems (MEMS): Due to their unique properties in the field of the mechanical as well as electronic MEMS is the emerging area in the field of nanoscience and technology. MEMS having small size and require a very less energy input to operate this applications. In MEMS on a single device thousand of wafers are fabricated. Due to this advancement MEMS used in energetic material as a micropropulsion materials. Microthruster, microactuators, pulse power generators and microdetonator are widely used as military applications.[15]



Scheme 2: Energetic micropropulsion

Initiators

Nanothermite material used in miniaturized actuation technology and it is fabricated with the silicon based bridge which converts electrical inputs into chemical inputs and provide energy in terms of joule. Bismuth oxide based thermite material was fabricated with microchip material and solder it at 47°C. Energy obtained from bismuth oxide based thermite material is 30 to 80 μJ . In this operation ignition time is less than 2 μs at high power rate.[16]

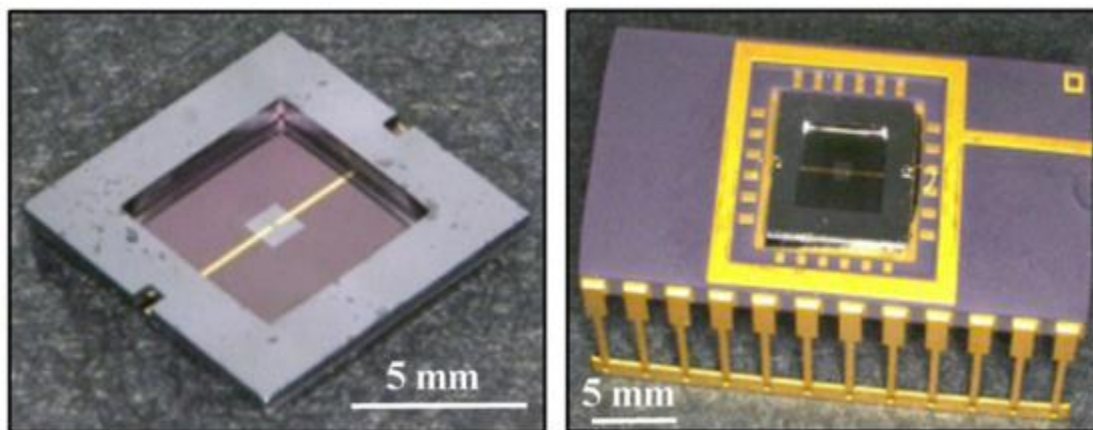


Figure 2 : (a) Photograph of assembled (b) packaged micro-initiator device

Conclusions

Different methodologies have adopted for the synthesis of nanothermite materials. Various applications of nanothermite materials were discussed. Role of different binders and their effects on thermite materials is also discussed.

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