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Extreme energies for material processing

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Extreme heat is an important factor for the processing of several high temperature materials: ceramics, alloys and high fusion point's elements. Extreme light originating from high power lasers represent a powerful tool for applications in material science and engineering physics. The application of high power lasers may be rewarding both for obtaining unusual alloys and complex materials, as well as high purity, high fusion point alloys. Several applications of intense lasers are suggested in the production of hydrogen from water, in the destroying of silica particles with the aim to reduce the concentration of dangerous particles in air, etc… Last but not least the preparation of new glasses with tailored properties, as well as development of new deposition methods for thin film preparation will be an important output of the application of intense laser sources.

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1. Introduction

In the last decades notable advances in the laser field have been obtained. Due to short pulses it is possible to get powers up to 1 PW and even higher. The extreme powers will permit to reach particle accelerations that can lead to velocities close to the light speed. A new physics is therefore at our fingers. ELI (Extreme Light Infrastructure) is planned as a powerful tool for generating not only high power light but also secondary beams, among them ultra-short particle bunches may thought as particularly useful for material sciences.

With the present day lasers it has been demonstrated that electrons with hundreds of MeV, protons and carbon ions with several MeV, and even 2.5 MeV neutrons can be obtained in short (sub-picoseconds) and intense ($>10^{12}$ particles) pulses. It is realistic to expect that an increase by three order of magnitude of the available power will result in much more intense particle pulses, higher energies, as well as in the possibility of heavier ions acceleration.

In the filed of materials science many experiments can be achieved with powerful energy sources.

In this paper a brief outline on the relevance of high energy sources in the processing of new materials is given. The prospective applications of the power laser enlargement in the field of materials science is envisaged as well.

2. Complex alloys and very high temperature processing

The aim of the preparation of very complex ceramics is to get new advanced materials with new properties including glass formation and controlled glass conductivity.

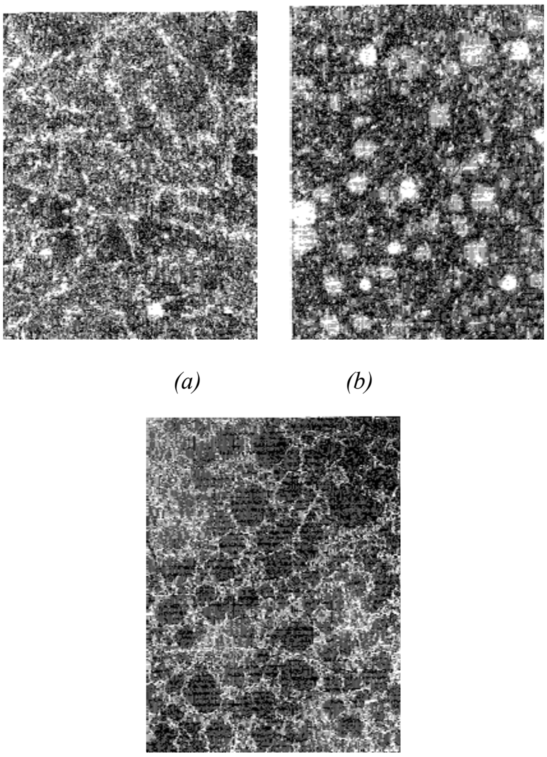
Twenty five different compounds of the elements with various cation radii have been mixed in a planetary mill for 2h. The cation composition was: B, Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Zr, Nb, Sn, Ba, La, Cl, Nd, Ta, Pb and Bi. Calcium, Strontium, Barium and Manganese were introduced as metal carbonates. Copper, Nickel and Cobalt were introduced as hydrocarbonates and Iron as iron hydroxide (FeOOH). The other elements enter the mixture as oxides. All the cations species in the mixture were in the rigorously equal amount (4 at. %). The slurry containing the mixture was gently dried in an oven at 150 ^{o}C. The yellow powder thus obtained was pre-fired at 850 ^{o}C for 1h and then the product was again milled for 2h.

Disc shaped pellets were pressed in a steel dye at 77.6 MPa. Finally pellets of 1 cm in diameter and 3 mm in thickness were put on ZrO_2 plates and fired in an oven at 1000, 1100, 1300, 1400 and 1500 ^{o}C for half an hour in air. The highest firing temperature was in the vicinity of the melting point of the ceramic mixture.

The polished discs were analyzed by X-ray diffraction, density, microhardness, electrical conduction, thermoelectric and magneto-resistance properties.

2.1 Experimental results

The micrographs on the surface of the sample are shown in Fig. 1. The values of the lattice parameters as a function of firing temperature are given in Table 1 and the activation energies for conduction in Table 2



(a) *(b)*

(c)

Fig. 1. SEM micrographs on ceramic powder fired at various temperatures for 2 h: (a) 1100 ^{0}C, (b) 1300 ^{0}C and 1400 ^{0}C. Magnitude: - 20μm.

Table 1. Lattice parameters of the crystalline phases.

Firing temperature (^{0}C)	Lattice parameter a(Å)	
	Main phase (fee)	Spinel phase
1100	5.346	8.452
1300	5.278	8.363
1500	5.240	-

Table 2. Electrical data for complex semiconducting ceramics.

Firing temperature (^{0}C)	Activation energy (eV)			Resistivity (Ωcm)
	20-120 ^{0}C	120-200 ^{0}C	200-300 ^{0}C	
1100	0.26	0.30	0.35	6.9×10^5
1300	0.26	0.31	0.33	6.2×10^5
1400	0.30	0.39	0.39	1.2×10^8
1500	0.30	0.45	0.45	4.2×10^6

2.2 Discussion of the results

In spite of the high number of cations with broad distributions of radii, the resulting crystalline lattice is a cubical spinel. Only traces of other spinelic phase are observed in the sample fired near the temperature situated in the vicinity of the melting point of the composition.

In spite of the crystalline cubic structure obtained in this complex ceramics, wev must admit that the distribution of the metallic atoms in the interstices of the oxygen sublattice is random.

Such type of disorder embedded into a perfect cubical order of the anion matrix (based on the oxygen atom packing) is unusual and we envisage special applications of this complex material related to its hardness, corrosion useful resistance, etc.

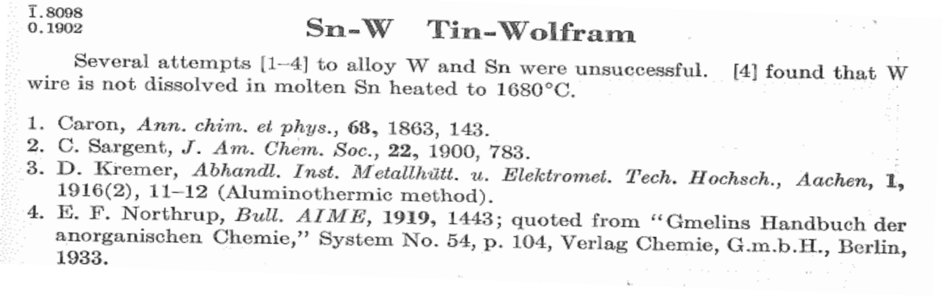
In the case of heating by classical sources of heat there are several shortcomings: high impurification, low heating and cooling rates, and last but not the least limited firing temperatures.

A powerful laser beam is suggested to improve drastically the preparation conditions of the complex ceramics.

The defect engineering in these materials will allow finding and developing new applications.

3. High fusion point alloys

A series of high fusion temperature elements are difficult to obtain with the classical procedures of melting. For example tungsten alloys with tin or other low temperature elements are practical impossible to obtain. That is why the phase diagram W-Sn practically does not exist. (see Fig. 2)



I.8098
0.1902

Sn-W Tin-Wolfram

Several attempts [1–4] to alloy W and Sn were unsuccessful. [4] found that W wire is not dissolved in molten Sn heated to 1680°C.

1. Caron, *Ann. chim. et phys.*, **68**, 1863, 143.
2. C. Sargent, *J. Am. Chem. Soc.*, **22**, 1900, 783.
3. D. Kremer, *Abhandl. Inst. Metallhütt. u. Elektromet. Tech. Hochsch., Aachen*, **1**, 1916(2), 11–12 (Aluminothermic method).
4. E. F. Northrup, *Bull. AIME*, **1919**, 1443; quoted from "Gmelins Handbuch der anorganischen Chemie," System No. 54, p. 104, Verlag Chemie, G.m.b.H., Berlin, 1933.

Fig. 2.

With the advent of new powerful laser sources the preparation of alloys of different elements could be facilitated. New binary alloys W-Sn treated in oxygen atmosphere are expected as excellent materials for gas sensing devices.

4. New method for thin film formation

The high power laser sources are important in the development of new methods for the deposition of thin films: the explosive evaporation and deposition.

The rapid evaporation of the targets will allow to obtain more homogeneous thin films, even chemically complex targets are used in the deposition process.

5. Fractioned decomposition of the alloys

In many cases it is very difficult to perform the elements separation in alloys.

A method of separation is imagined by means of high power lasers. At high energies, the laser pulse energy will give rise to different evaporation rate of the elements in a target. The clusters of the controlled size and composition could be separated e.g. in an electric and/or magnetic field. The separation of ceria earths (lanthanoids) could be made feasible in the intense laser beams.

6. High temperature glasses

The use of high intense lasers will allow ~~for~~ a very rapid heating up to melting temperature, followed by rapid cooling. Thus new glasses could be prepared in the future.

Metglasses and high fusion point glasses will be a major output in the field of glass physics.

7. Studies of the materials in high power laser pulses

The study of thermal shocks thermal diffusion, as well as the photonic shock is possible only with intense laser pulses. New physics will be put, therefore, at work.

8. New method for hydrogen production

High laser pulses will be of interest in the decomposition of water. Short powerful laser pulsed will initiate the instantaneous decomposition of water followed by a rapid separation and collecting of hydrogen as a raw matter for the use in fuel cells.

9. Transformation of large size particles in nanometric ones

The atmospheric instabilities resulting in tornadoes that introduce in atmosphere a high number of particles, as well as the activity of volcanoes could produce a high concentration of particles in the air, a danger for the life on earth. Recently the reactivation of a volcano in Island launched an enormous quantity of pollutants in the earth atmosphere. Rough estimations show that the main fraction of solid pollutant from the ejected particles and gases is SiO_2 (58 %). The remainig part is formed by SO_2, CO_2 and HF.

The SiO_2 particles are very dangerous not only for health, but also for the modern turbo-jets whose motors could be stopped during flight because of the damage produced by very hard micrometer particles.

One of the solution to this problem is to eliminate in a way or other the particles of SiO_2 from the atmosphere. The optical spectrum of the silica particles either in crystalline form (quartz) or in glassy form (as usually in the volcanic processes where high temperature and high cooling rates of the particles occur) is shown in Fig. 2.

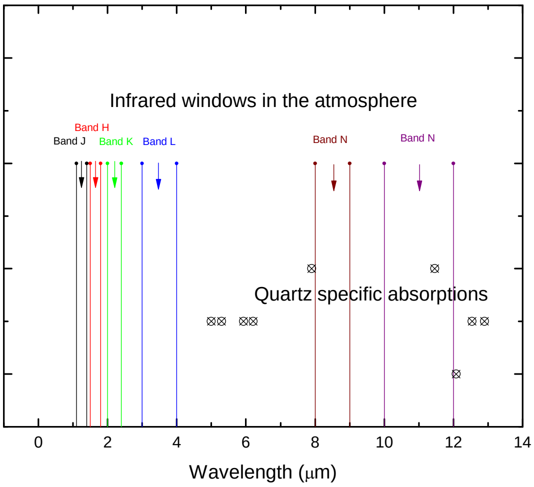


Fig. 2 Absorption spectrum of silica particle.

The absorption spectrum shows that there exist several wavelength domains where the absorption in silica is very high. Some domains enter (at least partially) in the region of the atmosphere windows for infrared light. The spectra for vitreous silica and neutron-irradiated silica show two regions of absorption which are not present in the crystalline form — a strong band is observed near 950 cm^{-1} and a broad band from 600–800 cm^{-1}. Optical data for non-crystalline Si, SiO, $SiO_x(x=1{\cdot}5)$ and SiO_2 are presented and analyzed for the energy region 1 to 26 eV. The results indicate that amorphous substances of all intermediate compositions between Si and SiO_2 can be formed and that these materials are not simple mixtures of Si and SiO_2 but rather the two atom species are blended on an atomic scale. More specifically, the Si bonding is tetrahedral (perhaps highly distorted) and of the type $Si-(Si_vO_{4-v})$ where the distribution of atoms is essentially statistical. Further it is found that the optical properties of these layers are determined by the presence and grouping of Si−O and Si−Si bonds and that clusters of like bonds of the dimension of a $Si-(Si_4)$ or $Si-(O_4)$ tetrahedra have optical properties comparable to those exhibited by amorphous silicon or quartz, respectively, 'in bulk'.(see Journal of Physics and Chemistry of Solids, 2010)

Pulverized quartz absorbs characteristically certain bands of radiation in the IR range of 2.0-15.0 um. Sedimentary and metamorphosed quartz absorbs similarly. Specific absorption occurs at 5.0, 5.3, 5.93 and 6.21 um.

High fairly uniform absorption occurs from about 7.9 to 9.9 um from where it decreases with longer wavelength until it reaches a minimum at about 12.08 um. At still longer wavelengths it absorbs at 12.54, 12.9 um and more intensely at 11.46 um.

Variation in particle size distribution from 15 to about 75 um in cross section affects the degree of IR absorption

The absorption is a function of crystal structure.

[Absorption of infrared radiation by pondered silica minerals. W. D. Keller, E. E. Picket, 1950]

Infrared windows in the atmosphere:

1.1-1.4um	Band J
1.5-1.8 um	Band H
2.0-2.4 um	Band K
3.0-4.0 um	Band L
8.0-9.0um 10.0-12.0 um	Band N

By using a powerful laser beam the micrometer size particles of silica could be disintegrated in many nanometric particles for special wavelengths emitted by high power sources.. Thus the process of falling the ashes towards the earth will become slower. In any way the particle cleaning in some region of the atmosphere could be made possible.

10. Conclusions and perspective for materials science

The use of extreme energy in materials science and technology gives the possibility to synthetize new materials with novel properties. The advent of new powerful laser pulses will open the way to new materials and new physics which will be put at the basis of the processing of the solids, liquids and even gaseous matter.

Moreover, the ultra short time extent of these laser pulses will enable extremely short-lived movements and reactions with the characteristic time of the order of attoseconds (10^{-18} s) or even zeptoseconds (10^{-21}s) to be observed in real time.

The increase of the conversion efficiency of laser light into coherent X-rays will be of great interest creating the possibility to generate ultrafast coherent hard X-rays with a table-top system that will revolutionize scientific research in microscopy, molecular dynamics, biotechnologies and nanotechnologies.

Such ultra intense laser pulses could also reduce dramatically the distances required by particle accelerators to produce particle or radiation beams that can be later used to create new spectroscopic methods for the wonderful world of materials science. This technical facility will have a successful impact, from physics and chemistry through biology and medicine to future information technologies.

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