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ЛАБОРАТОРНАЯ ТЕХНИКА

EXPERIMENTAL STUDY OF EXPLODING WIRE METHOD FOR PRODUCTION OF METAL NANOPARTICLES

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In an effort to characterize the exploding wire method for efficient production of nanoparticles, we are involved for studying this method in our laboratory. The copper wire of 0.26 mm diameter was exploded inside an enclosure made off stainless steel. The explosion was done by passing electric current through the wire by discharging the capacitor. In this paper we discuss the behavior of the electrical circuit in explosion process and the production of the nanoparticles after explosion.

INTRODUCTION

In exploding wire method, the metal wire is exploded instantaneously by the current flowing through the metal wire due to the discharging of the capacitor. Due to this explosion, the metal core undergoes multiphase state like liquid/vapor or both and nanoparticles are formed due to the expansion of the liquid cluster and nucleation of vapour. The amount of energy deposited into the wire is important for the formation of the nanoparticles. Exploding wire method is used for many applications like opening switches [1] named as fuses, in the inductive energy storage [2], discharge loads of X-pinch [3] or Z-pinches [4] and the production of nanoparticles [5, 6].

Here we are reporting the production of copper oxide nanopowder by exploding wire method. Cupric oxide (CuO) is a p-type semiconductor and has attracted much interest because it is the basis of several high-temperature superconductors [7]. But producing single phase CuO is a difficult task. Study of the electrical behavior of the exploding wire becomes important for getting the particles of desired size as well for obtaining the single phase copper oxide. Initial explosion dynamics of the wire depends upon the current wave form, the peak voltage and the energy deposited in the wire.

We are studying various electrical characteristic of the experimental set up for the exploding wire method for the production of nanoparticles by using copper wire. The determination of experimental parameters and details of experimental set up is described in the section-2.

EXPERIMENTAL SET UP

The explosion of the wire depends upon the cross section of the wire. The cross section needed for the explosion to occur can be calculated from the formula for the action integral:

$$a = \frac{1}{s^2}\int_0^{t_b} I(t)^2 dt = \gamma \int_{e_0}^{e_V} \frac{1}{\rho(e)} de.$$

Here a is called the action integral of the material and as the left hand side of the integral is solely dependent on material properties and hence considered constant for particular material; s is the cross section of wire; $I(t)$ is the current flowing into wire at particular time; γ is the density of the material; $\rho(e)$ is the resistivity of the material and typically function of deposited energy; t_b is the time of burst, e_0 and e_V are internal energy at initial and at the time of vaporization.

Action for copper is $1.31 \cdot 10^{17}$ A^2 s m^{-4}. However for exploding wire experiments, a needs to be multiplied by a factor k_1, where $1 < k_1 < 3$. For explosion of the wire, the action of the system should be nearly equal to required action of copper. The detail procedure of calculation of cross section from action integral has been explained by other authors [8]. Here to have the explosion at the charging voltage 12.5 kV, required diameter of wire was found to be ~0.26 mm.

Explosion process being different than the normal heating process, the formation of the nanoparticles is characterized by overheating factor. Exploding wire method is considered to be adiabatic in nature. The size of the nanoparticles depend upon the overheating [9] of the wire. The overheating arises due to high rate of energy deposition and delay in expansion of the heated wire. The overheating is defined as the ratio of the deposited energy before explosion to the specific sublimation energy. The energy deposited in the wire can be calculated by equation given below:

$$E(t) = \frac{\rho l}{s} I(t)^2 = \int V(t) I(t) dt.$$

The schematic diagram of the experimental set up is shown in the Fig. 1. One copper wire of diameter 0.26 mm was mounted through electrical feedthroughs

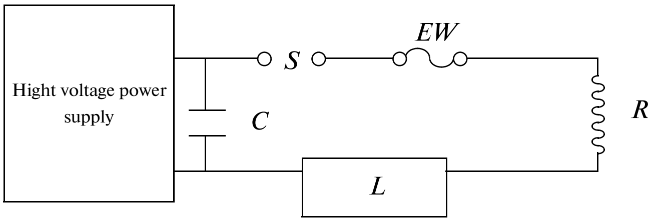

Fig. 1. Schematic diagram of the exploding wire circuit.

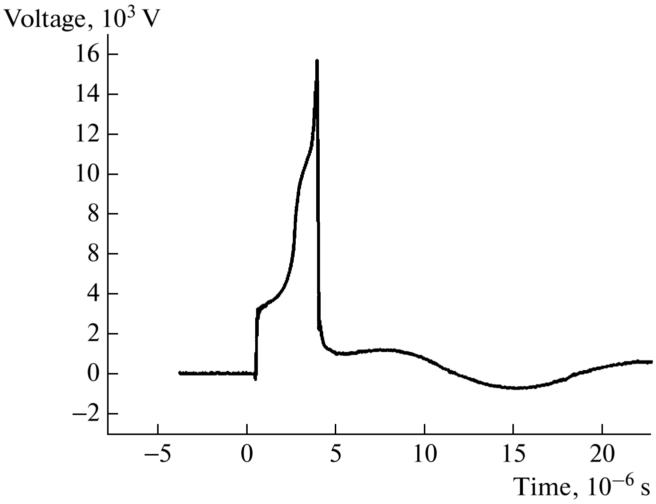

Fig. 2. The measured voltage across the wire.

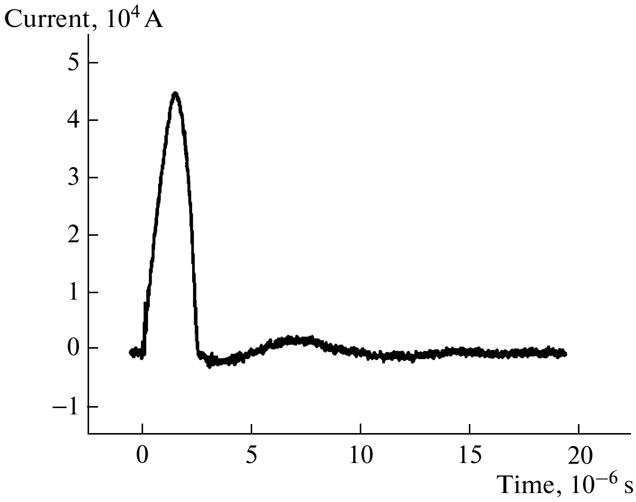

Fig. 3. The measured current in the wire.

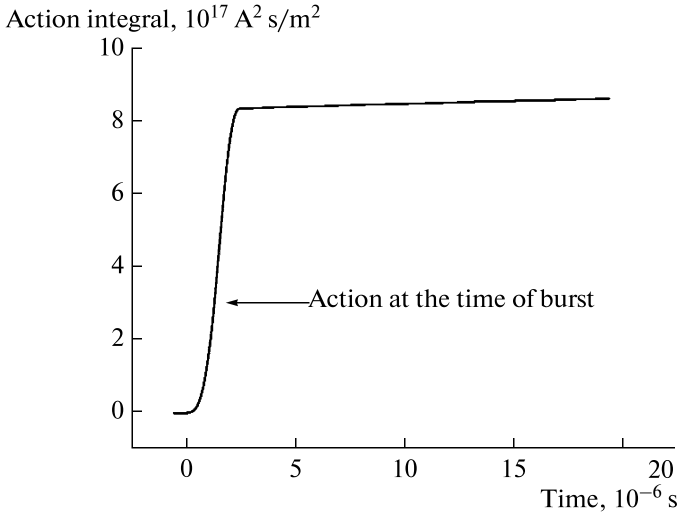

Fig. 4. Action into the wire.

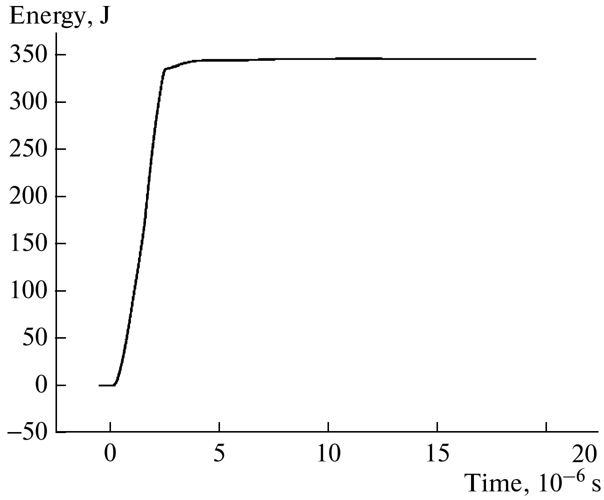

Fig. 5. The deposited energy into the wire.

inside a chamber made out of stainless steel. One capacitor of 7.1 μF capacitance was charged to 12.5 kV and the stored energy of the capacitor was discharged into the wire by switching a spark gap. The development of the current through the wire depends upon the inductance of the circuit.

The lesser the inductance, the more current can flow through the wire. To reduce the inductance of the circuit, the connecting path between the capacitor output terminals and the end of the wire was taken care of by using multiple parallel cables. For electrical connection, we had used URM 67 co-axial cable. The inductance of the circuit was measured as 500 nH. The arrangements were made to measure the voltage and current across the wire. The voltage probe was resistive divider which was placed across the wire. The current monitor was placed in the periphery of the discharging cable connected between capacitor and the copper wire. The explosion was done in ambient conditions.

For the collection of the particles, sample holders made of glass, were placed inside the chamber horizontally at a distance of 13 cm from the wire. After explosion the sample holders were taken out and particles were analyzed by X-Ray Diffraction (XRD) for the chemical composition and Transmission Electron Microscope (TEM) for their size. For XRD we had used a Seifert system Model XRD3000PTS where as for TEM we had used Philips Tecnai 20.

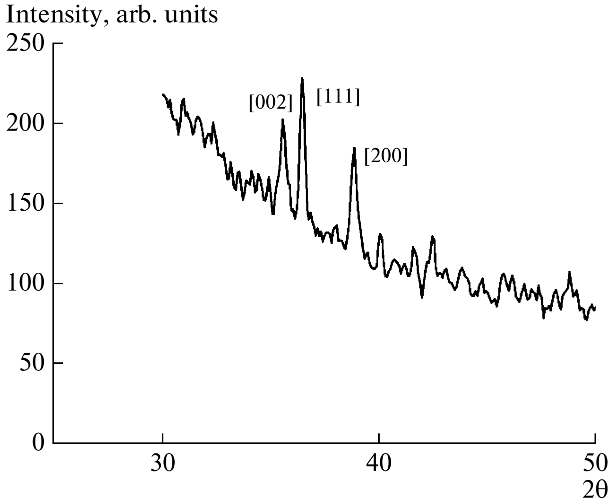

Fig. 6. XRD analysis showing planes of cupric oxide.

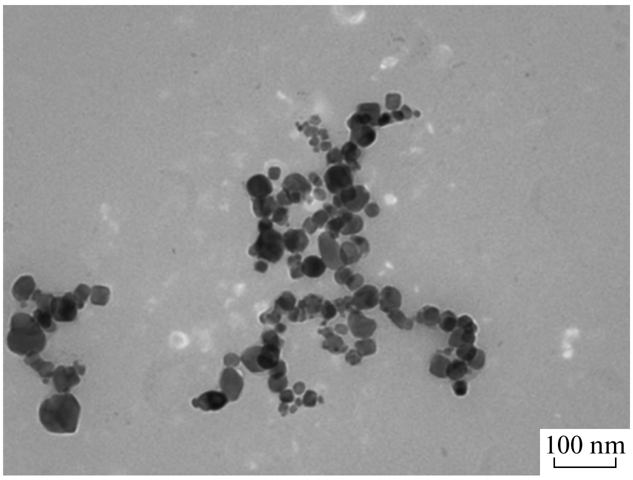

Fig. 7. Image of the TEM analysis.

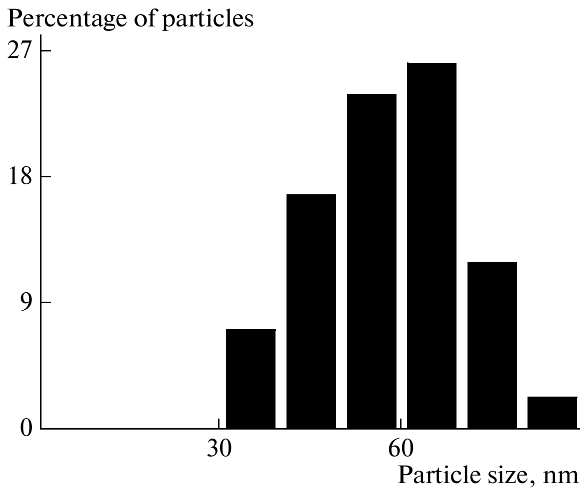

Fig. 8. Particle distribution.

RESULTS

The measured peak voltage and current are shown in the Fig. 2 and 3 respectively. The action into the wire was measured experimentally by taking the current curve. The time of the burst is the time where the voltage peak occurs. The action integral at the point of the burst is shown in the Fig. 4. At the voltage peak at 15 kV, the action into the wire was found to be $3 \cdot 10^{17}$ $A^2 \cdot s/m^2$. Energy deposited into the wire is shown in Fig. 5.

Ratio of energy deposited to specific energy of sublimation is known as the overheating factor (k) is an important parameter for the production of nanoparticles. The sublimation energy of the wire taken in our case is calculated to be 212 J. For our case over heating factor is well above the unity.

The XRD spectrum as shown in the Fig. 6 shows the sample consisting of various planes of cupric oxide. The Fig. 7 shows the image of the TEM analysis. Particle distribution calculated from the multiple images of TEM is shown in the Fig. 8. Most of the particles fall in the range of 40–70 nm.

CONCLUSION

Electrical explosion of the metal wire is found to be useful for production of nanoparticles. This process is ecologically safe. This has the potential for high production rate with relatively low energy consumption by proper designing of the experimental set up. The distribution of the size of the nanoparticles could be controlled by proper selection of the charging voltage of the capacitor and the inductance of the circuit. In our future studies we will concentrate to get narrow distribution of particle size.

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