Chapter 39

Metal Nanoparticles by Pulsed Explosion Technique

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Nanopowder are the material whose individual particles are in nanometer range. Nanoparticle consists of the atoms and molecules which are bonded together to form the structure whose size varies between 1 nm to 100 nm range. These cannot be detected by human eyes. But it shows significant different properties from the same bulk material. By European commission definition, we can say one sample to consist of nanoparticles if at least half of the particles in the sample are in nano range in the measured size distribution. Many nanoparticles are made up of only few hundred of atoms. As we go to atomic scale, physical and chemical properties changes because of large surface area to volume ratio. Nanoparticles being very small, has larger surface area to volume ratio than bulk one. Because of their small size, it has the ability to confine their electron and produce quantum effect. This feature helps nanoparticles to develop different physical, optical and chemical properties. For example Copper with size less than 50 nm is very hard with drastically different performance in terms of ductility than bulk one. The melting temperature of the gold nanoparticles decrease drastically to 300 degree centigrade, compared to bulk gold whose temperature is 1064 degree centigrade. Absorption of solar radiation is more which contain nanoparticles rather than small shit of thin film. Nano-materials can exist naturally in nature or can be engineered for particular requirements. Due to the ability to engineer material the use of nano-material varies over the wide span from industry, cosmetic to health care and air purification. In health care system, one major use of nano-particles is drug delivery at particular organ, may be at the site of growth cancerous shell or at the damaged arteries. In aerospace, carbon nano-tube is used to make aircraft wings. Carbon nano-tube is useful for manufacturing of bat in the sports industry to make the bat lighter to improve performance.

39.1. Methods of production of Nano-particles

In the past few centuries, many methods have been developed for the production of nanoparticles. Two production processes are identified as top down and bottom up method. Top down method comprises rapid quenching, milling and lithography. It can be subdivided into two categories; Dry and wet grinding. These methods are not suitable to produce Nanoparticle of controlled size and shape. Bottom up process involve the building of the material from the bottom i.e atom by atom, cluster by cluster and molecule by molecule [1]. Various methods for the production of nanoparticles are follows.

39.1.1. Chemical method

Using chemical reductant in aqueous and non-aqueous solution, there are many methods identified for production of nanoparticles. These are called chemical methods. Chemical method includes electrochemical method [2], photo chemical method, radiolytic methods [3].

39.1.2. Physical method

Physical method comprises of plasma method, chemical vapor deposition method, Microwave irradiation, pulsed laser method Gamma radiation technique.

39.2. Pulsed explosion technique

Pulsed explosion technology is the promising method for the production of nanoparticles of different metals alloys which can be formed as wire. This involves the passage of high density current through a thin wire for a small period of time. With this wire explodes and produce explosion product, which form nanoparticles when explosion vapor passes through a gas atmosphere. It has high energy efficiency as it loses very small heat while the process. System useful to produce nanoparticles of narrow distribution. This method is suitable for the production of nanoparticles of metal, alloys, oxide and nitride [4]. Schematic diagram of pulsed explosion technique is shown in Figure 39.1.

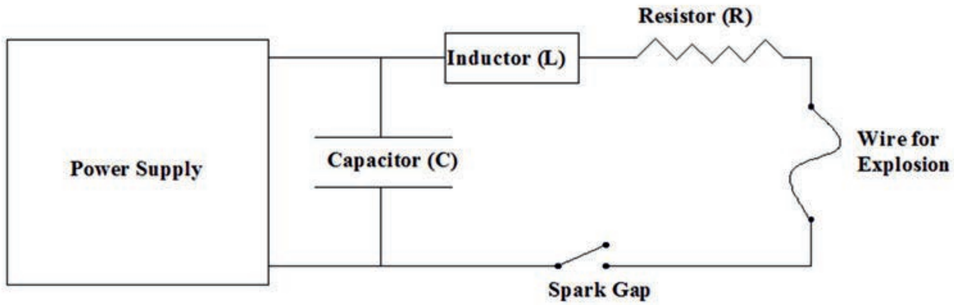

Figure 39.1. Schematic of pulsed explosion technique.

39.2.1. Theory

Pulsed explosion technique for the production of nanoparticles is one LCR circuit. Copper wire of 0.26 mm diameter was decided to be exploded by charging capacitor of 7.1 micro farad to 9 kV and discharging the energy into copper wire. Time period of the ringing curve was found to be 14 micro second.

System inductance is given by $L = \frac{T^2}{4C\pi^2} = 700$ nH (39.1)

Resistance of the circuit is given by $R = \frac{4L}{T} \ln \frac{V_2}{V_1} = 0.07$ Ohm (39.2)

For our case it was found that $R < 2\sqrt{\frac{L}{C}}$. So circuit was under damped circuit.

In this technique, the diameter of the wire is decided from action integral given in equation 39.3 [5].

$$\frac{1}{s^2}\int_0^{t_b} I(t)^2 dt = \gamma \int_{e_0}^{e_v} \frac{1}{\rho(e)} de = a \quad (39.3)$$

s is the cross section of the wire, I(t) is the current injecting into wire for a given time. γ is the density of the material, $\rho(e)$ is the resistivity of material which is a function of internal energy e, a is the action integral of the material. Action integral of copper is 1.31×10^{17} A^2sec m^{-4} [6].

Length of the wire decided by equation 39.4

$$l_{wire} = \frac{\vartheta W_{source}}{w_{total} \cdot \gamma \cdot s_{wire}} \quad (39.4)$$

$$w_{total} = c_s(T_m - T_0) + h_m + c_l(T_b - T_m) + h_v \quad (39.5)$$

c_s and c_l are heat capacities of solid and liquid. h_m and h_v are heat of melting and vaporization. T_0, T_m and T_b are initial temperature, temperature at the time of melting and temperature at the time of boiling respectively.

39.2.2. Observation of explosion in different pressure range

For each set of experiment pressure value was varied from 4.2×10^{-2} mbar to 1 bar with nitrogen. The current was measured by current transformer and voltage was measured by voltage probe. Current and voltage waveform are shown in Figure 39.2-39.4. Energy deposition for different pressure is shown in Figure 39.5 [7]. At 4.2×10^{-2} mbar 120 Joule of energy was deposited into wire, which is not sufficient even to melt the wire and it was used to break the surrounding medium. When the pressure was increased to 2.3×10^{2} mbar, 150 Joule energy was deposited into wire and the wire exploded producing micro size particles. Ringing behavior of current waveform shown in (Figures 39.2 & 39.3) shows that less energy is deposited into wire for which circuit behaves as a shorted LC system [7]. For pressure of 1 bar, energy deposited was highest i.e. 250 Joule. As observed in (Figure 39.4) most of the energy is used for current interruption [7]. At this stage the wire exploded and disintegrate into Nanoparticles.

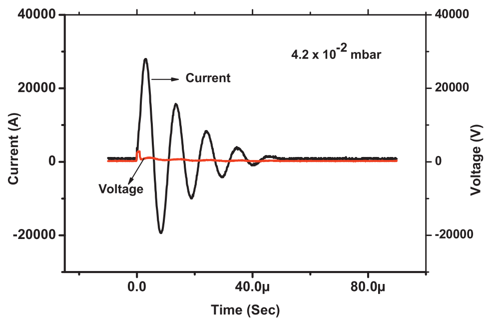

Figure 39.2. Voltage and current waveform at 4.2×10^{-2} mbar of nitrogen gas.

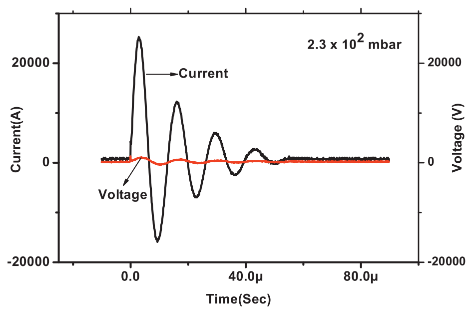

Figure 39.3. Voltage and current waveform at 2.3×10^{2} mbar of nitrogen gas.

39.2.3. Characterization of the sample

Sample was collected through gravitational method. Powder sample was characterized by X-ray diffraction. XRD spectrum is shown in Figure 39.6 [7]. XRD spectrum shows the presence of pure copper particles. Sample obtained at 2.3×10^{2} mbar of nitrogen gas pressure was characterized by optical microscope. Optical microscope image is shown in Figure 39.7 [7]. It confirms the presence of microparticles. Sample collected at 1bar pressure was characterized by transmission electron microscope. TEM image shown in Figure 39.8 confirms the presence of nanoparticles [7].

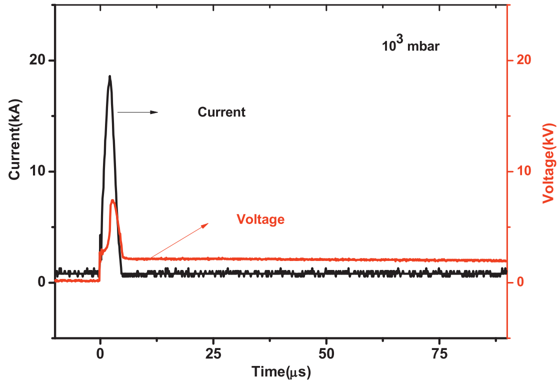

Figure 39.4. Voltage and current waveform at 10^3 mbar of nitrogen gas.

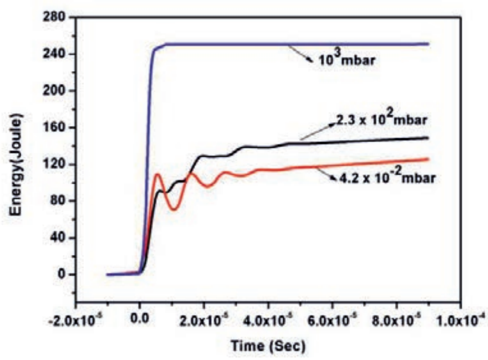

Figure 39.5. Energy deposited into the wire during wire explosion for various pressures of nitrogen gas.

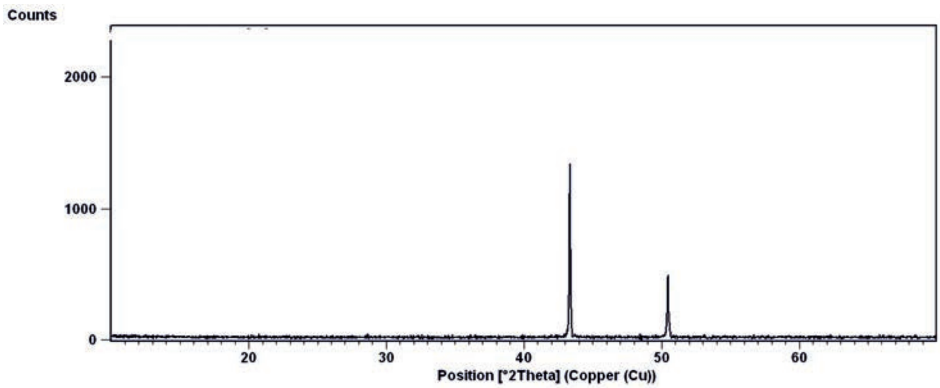

Figure 39.6. XRD spectrum for the exploded material.

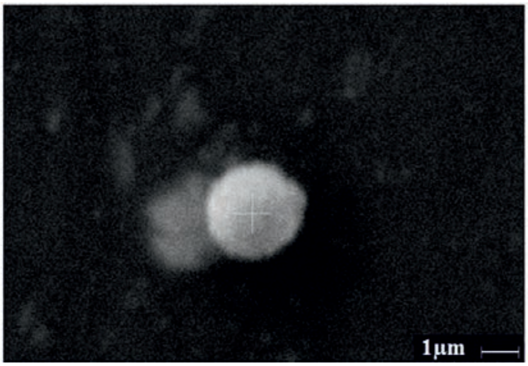

Figure 39.7. Optical microscope image of exploded material at 2.3×10^2 mbar of nitrogen gas pressure.

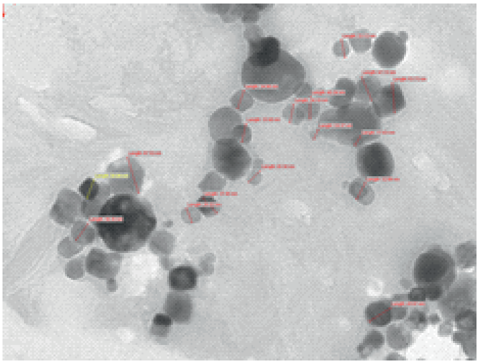

Figure 39.8. Transmission electron microscope image of nano-particles.

39.3. Conclusion

Energy deposition in the pulsed explosion technique depends upon the pressure value surrounding the wire. For lower pressure, as the resistance of surrounding medium becomes low resistive path than wire, current flows in the medium to create break down in the medium. The wire remains intact. If the pressure surrounding the medium increases, current flows more in the wire creating microparticles. At pressure of 1 bar, maximum current goes into the wire by which it disintegrate into nanoparticles. Pure copper nanoparticles as revealed from XRD image is due to unstable bonding of copper and nitrogen.

References

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