Pulsed Plasma Synthesis of Nanoparticles

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Outline

(1) Introduction

(2) Objectives

(3) Experimental Setup

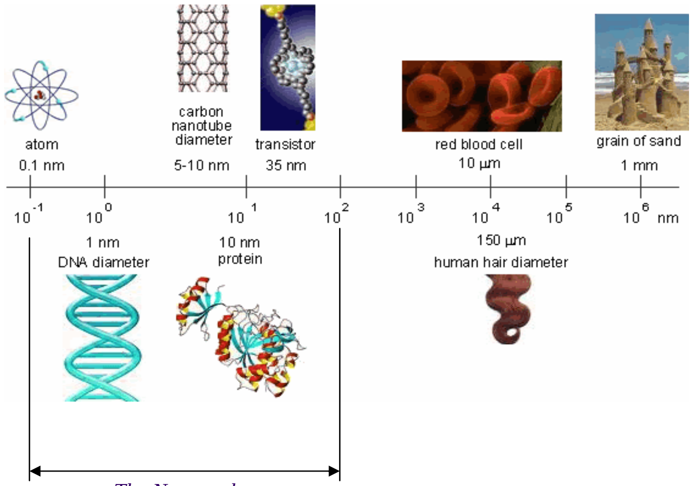
(4) Experimental Parameters

(5) Results and Analysis

(6) Conclusions

(1) Introduction

(a) The Nanoscale



The Nanoscale

Nanoscale: dimension from around 100 nm down to the size of atoms, which is approximately 0.1 nm.

1 nanometer ≈ 5 silicon atoms aligned in a line.

(b) Nanostructure material

(i) Have one or more of its dimension falling in the nanoscale.

Examples: nanoparticles, nanotubes, nanowires, nanolayers and etc.

(ii) Exhibit distinguish properties due to:

(a) the relatively large surface-to-volume ratio and

(b) the quantum effects that take place at very small scale

Examples:

(1) nanoparticles dimensions which are below the critical wavelength of light may enable light to pass through and results in the transparent property of the material.

(2) nanoparticles will have a higher catalytic efficiency compared to their bulk form due to their higher surface-to-volume ratio.

(c) Fabrication of Nanostructure Materials

Top-down approach:

1. bulk material is broke into smaller pieces using mechanical, chemical or other form of energy.
2. Examples: high-energy ball milling, etching, laser-ablation and electrical explosion.

Bottom-up approach:

1. atomic or molecular species are assembled into nanomaterials.
2. Examples: sol-gel processing, chemical vapour deposition (CVD) and plasma spraying synthesis.

(d) Pulsed Plasma Synthesis

Pulsed discharged system > Plasma > Nanoparticles (0.1 – 100 nm).

Examples : (a) Electrical explosion of wire, (b) Vacuum arc discharge

(e) Wire Explosion Technique

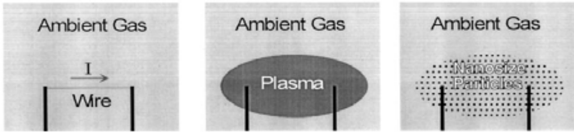
1998 – W. Jiang *et al.* produced pure metal, metal oxides and metal nitride nanoparticles through metal wire explosion in ambient gas of argon, oxygen and nitrogen respectively [1].

2004 – C. Cho *et al.* investigated the effect of energy deposited into the wire on the particle size distribution during a wire explosion [2].

2007 - R. Sarathi *et al.* studied the generation of aluminum nanoparticles by wire explosion technique in nitrogen, argon and helium ambient at three different pressure, namely 25 mbar, 50 mbar and 1 bar [3].

2008 – T. K. Sindhu *et al.* proposed a modelling of the nanoparticles formation in the wire explosion process [4].

(f) Basic Principle



(a) Wire > inert or reactive ambient gas.

(b) High power pulsed current > Joule heating effect.

(c) Melt > Evaporate > Formation of plasma.

(d) Temperature and pressure differences > Expansion of vapour and plasma.

(e) Cooling > Nucleation > Nanoparticles.

(2) Objectives

I. To *study the creation of nanoparticles* by wire explosion technique under 10^{-2} mbar and 10^{3} mbar.

II. To *study the discharge characteristic* and *plasma emission* of wire explosion under 10^{-2} mbar and 10^{3} mbar.

(3) The Experimental Setup

(a) Pulsed discharge system

(i) Vacuum system

(ii) Wire explosion chamber

(iii)Charging unit

(b) Diagnostics tools

(i) Current Probe

(ii) PIN diode

(iii)Time-integrated spectrometer

(c) Particles collecting tool

(i) Silicon substrate

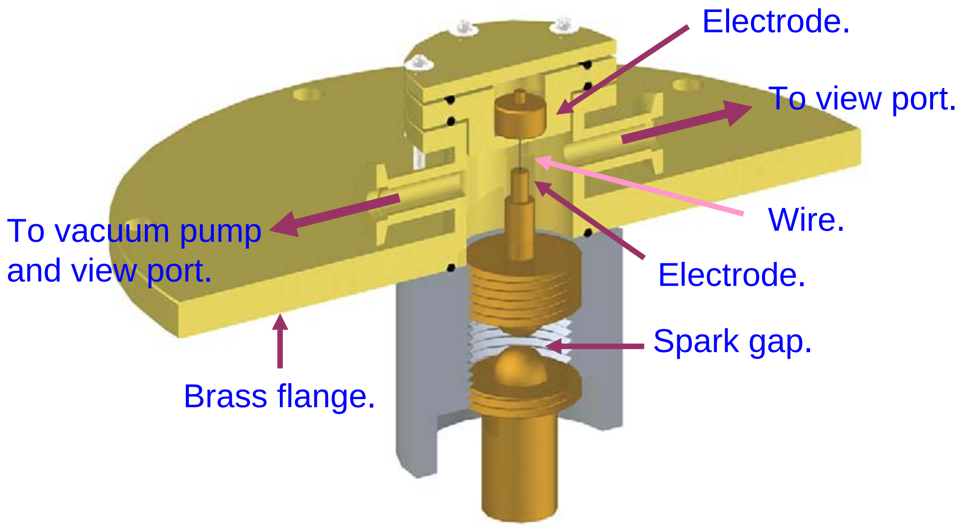
(a) Pulsed Discharged System

(Vacuum system, wire explosion chamber and charging unit)

1. Pirani gauge (To measure chamber's pressure).
2. Wire explosion chamber.
3. 1.85μF capacitor.
4. Connected to view port and rotary pump.
5. View port.
6. Coaxial cable connecting current probe with oscilloscope.
7. Cable connected to ground.

(ii) The Wire Explosion Chamber

(Spark gap, brass flange and electrodes)



(a) Cross-sectional view of wire explosion chamber.

(4) The Experimental Parameters

Wire Material:	Aluminum and copper wire
Wire diameter:	125 μm
Wire length:	8.5 mm

Capacitance:	1.85 μF
Charging voltage:	6 kV

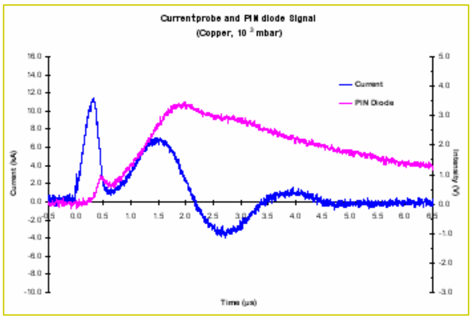
Ambience:	Air
Ambience pressure:	10^{-2} mbar and 10^{3} mbar

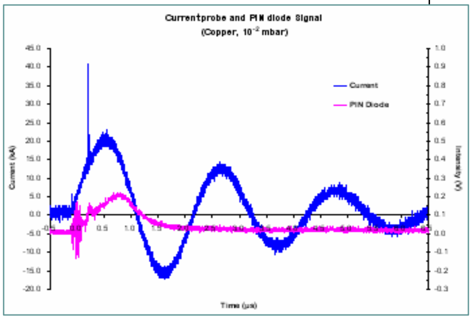
(5) Results and Analysis

(a) Current Signal and PIN Diode Signal

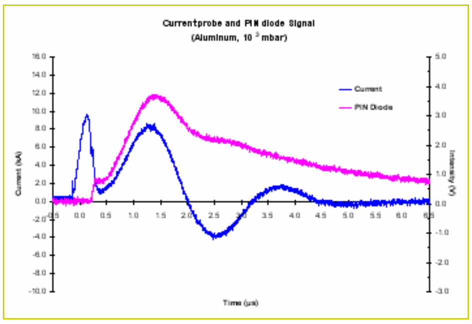
10^3 mbar | 10^{-2} mbar

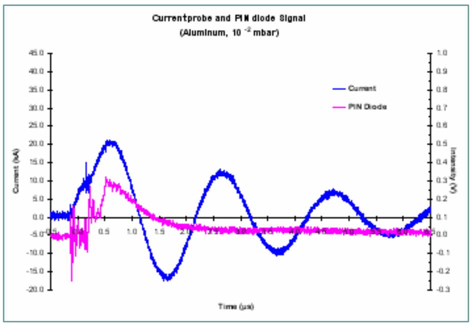
Copper



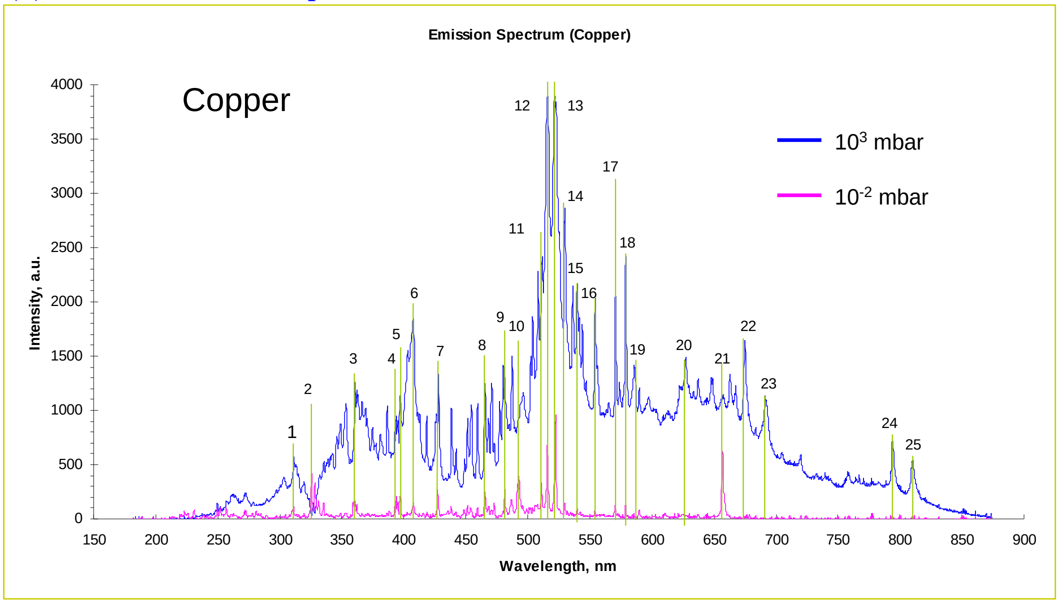


Aluminum

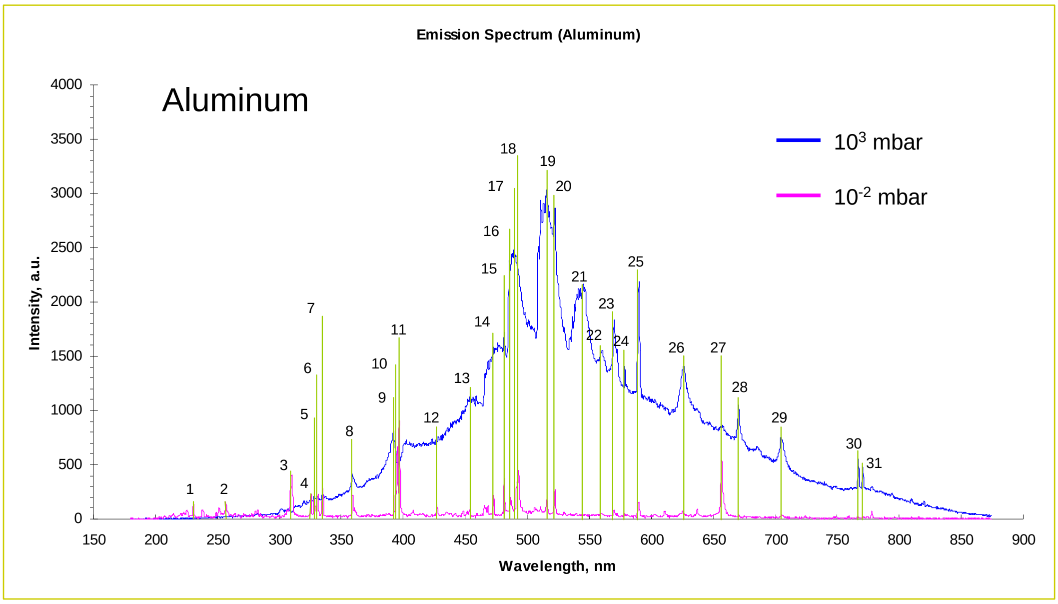




(b) Plasma Emission Spectrum



O^{+}	1, 3, 5, 6, 15, 23	N	18, 19, 22, 25	Cu	11,13
O^{2+}	2	N^{+}	8, 16	Cu^{+}	12, 20, 21, 24
O^{3+}	4, 9	N^{2+}	14	Cu^{2+}	7,10,17



Cu	6
Cu^{2+}	14, 18

O	31
O^{+}	3, 10,12, 16
O^{3+}	15

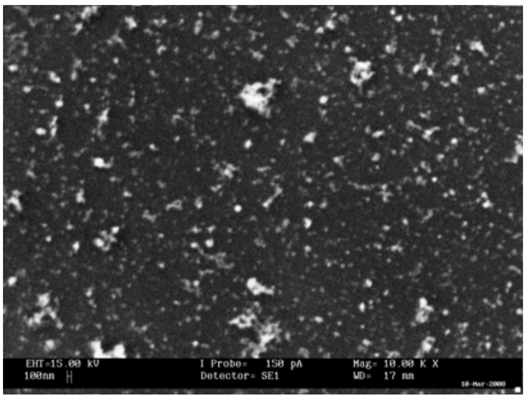
N	24, 28
N^{+}	9, 21, 25
N^{3+}	20
N^{4+}	13

Al	2, 5, 11
Al^{+}	7, 8, 17, 22, 26, 29
Al^{2+}	19, 23,27, 30
Al^{3+}	1, 4

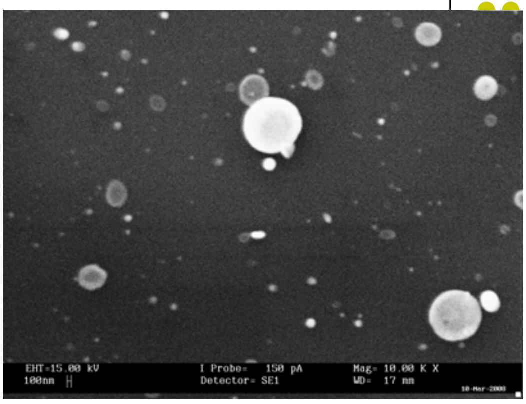
(c) Particles Morphology and Composition

Copper

10^3 mbar



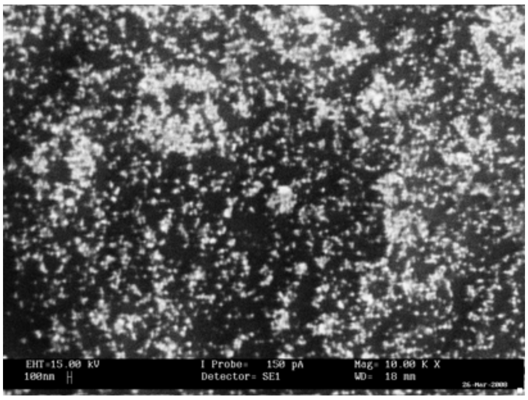
10^{-2} mbar



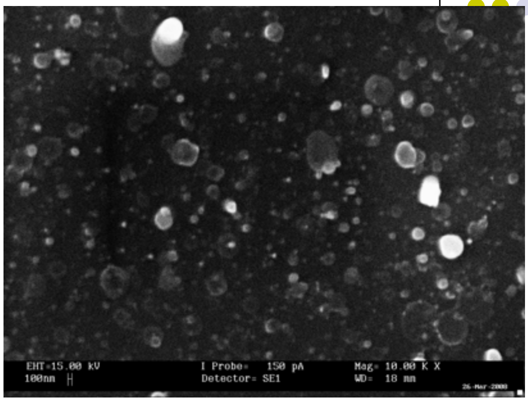
1. At 10^3 mbar wire explosion, oxygen and copper are the main elements that formed the particles.
2. At 10^{-2} mbar wire explosion, the main element is copper.

Aluminum

10^3 mbar



10^{-2} mbar



1. At 10^3 mbar wire explosion, oxygen and aluminum are the main elements that formed the particles.
2. At 10^{-2} mbar wire explosion, the main element aluminum.

(6) Conclusions

(i) At pressure of 10^{-2} mbar, particles ranged from approximately 100 nm to micron-sized are observed.

(ii) At pressure of 10^3 mbar, particles ranged from less than 100 nm to a few hundred nanometers are observed.

(iii) Pure copper and aluminum particles are obtained by wire explosion at 10^{-2} mbar.

(iv) For both pressures, Al, Al^+, Al^{2+} and Al^{3+} are presence during aluminum wire explosion while Cu, Cu^+ and Cu^{2+} are presence during copper wire explosion.

(v) The mechanisms for wire explosion at 10^{-2} mbar and 10^3 mbar have been investigated based on current probe signal and the plasma emission characteristic.

References

[1] W. Jiang and K. Yatsui, *Pulsed wire discharge for nanosize powder synthesis*, IEEE Trans. Plas. Sci., **26**(5), pp.1498-1501. (1998)

[2] C. Cho, K. Murai, T. Suzuki, H. Suematsu, W. Jiang and K. Yatsui, *Enchancement of energy deposition in pulsed wire discharge for synthesis of nanosized powders*, IEEE Trans. Plas. Sci., **32**(5), pp.2062 – 2067. (2004)

[3] R. Sarathi, T. K. Sindhu and S. R. Chakravarthy, *Generation of nano aluminum powder through wire explosion process and its characterization*, Materials Characterization, **58**(2), pp.148 – 155. (2007)

[4] T. K. Sindhu, R. Sarathi, and S. R. Chakravarthy, *Understanding nanoparticle formation by a wire explosion process through experimental and modeling studies*, Nanotechnology, **19**(2), pp.025703. (2008)

Thank you.