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Preparation of Aluminum Nanoparticles by Exploding Wire in Different Liquids

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Abstract: The present work, provides a simple technique for the production of aluminum nanoparticles based on the explosion of thin aluminum wires in different liquids (distilled water, ethylene glycol and cyclohexane) by applying 36 Volte DC to two electrodes, one in the form of thin wire and the other in the form of plate and bring them to in touch mechanically. The nanoparticles are characterized by x-ray diffraction and UV-Visible spectroscopy. The x-ray diffraction results reveal that the nanoparticles continue to routine lattice periodicity at reduced particle sizes. The UV-Visible absorption spectrum of the liquid solution of the aluminum nanoparticles shows no characteristic Surface Plasmon Resonance (SPR) peak in the visible region. The TEM and SEM images show that the aluminum nanoparticles have narrow particle size distribution ranged from 20 to120 nm with average particle size 80 nm. The aluminum nanoparticles prepared in water and that prepared in ethylene glycol show, no difference in their average particle size and distribution, while those prepared in cyclohexane show smaller sizes. It was observed that the particles have a little irregular shapes and low agglomerate was observed.

Keywords: Silver nanoparticles; exploding wire; plasma.

1.Introduction

Nanoparticles have novel physical and chemical properties [1] and they have many applications; such as optoelectronic materials, magnetic fluids, composite material, fuel cells, pigments and sensors [2, 3]. Aluminum nanoparticles can be used in many applications; such as, in vitro cancer therapy and imaging [3, 4]. Metal nanoparticles were produced by laser beam [5], electron beam, mechanical milling [6], electrical exploding wire [7, 8] chemical vapor deposition, plasma chemical vapor deposition [9, 10]. In this work the nanoparticles produced through the dominant mechanism of spark explosion which is an adaptation of the phenomena called electro-explosion of wires, where both electrodes produce the particles, while they were surrounded by liquid medium. The two electrodes melted vaporized and turned into plasma, when high current density passes through the electrodes as they just contactmechanically.

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The metal plasma expands with supersonic velocity creating shock wave in the surrounding medium. Finally nanoparticles where formed by the interaction withthe liquid. The vaporized particles where condensed more efficiently in the liquid than in ambient air.Electrical explosion of wire (EEW) in gas have been applied to synthesize many kinds of nanomaterial including metal and compounds. More recently, this method has been developed to synthesize metal nanoparticles in a solution, compared with the EEW in gas; EEW in liquid has been less investigated. It has become one of promising methods for synthesis metal nanoparticles because of its simplicity, effectiveness and low cost. Synthesis of nanoparticles in liquid needs no vacuum system. In addition, nanoparticles can synthesize in water or in any arbitrary solution without impurities [11-13]. Properties of nanoparticles synthesized by EEW depend on many parameters, which include wire properties such as wire dimensions (diameter and length) and material, characteristics of the electrical circuit, and ambient medium. Among these, ambient liquid medium is an important parameter, which is much affecting the properties of nanoparticles. In the present work we provide a simple apparatus for the production of aluminum nanoparticles based on the explosion of thin aluminum wires in different liquids and report the effects of explosion surrounding medium on the particle sizes, and distribution, A change of the ambient medium in explosion process presents a simple and flexible technique to modify the properties of nanoparticles [14-16].

2. Experimental Work

The present work discloses a simple and efficient apparatus for carrying out the wire explosion, to produce large quantities of metallic nanoparticles. The explosion was carried out with 36 Volt DC. The electro-explosion of wires (EEW) is carried out in a reaction vessel of (500 ml) prepared to house the two electrodes and the medium in which the explosion is carried out. The exploding wire is aligned to the correct geometry through glass tube wire guide as shown in Fig. 1 Hard teflon blocks, used as an insulator as well as it to withstand the explosion conditions, to fix the two electrodes. The metal plate was slide through two groves on the face of one block and the wire was passed through the glass tube attached to the other block placed opposite to the previous one. The two electrodes were connected through thick copper wires to the two terminals of the 36 V batteries.

The electrical circuit remains open until the electrical contact is made by the thin wire when touching the plate mechanically, resulting in the wire explosion through a nonlinear process in a very short time due to high current density passes through the wire; this in turn opens up the circuit for another explosion process. Al wires of purity 99.998%; Alfa Aesar and plates (dim: 70, 40, 2 mm; Purity: 99.998%; Alfa Aesar) used for the explosion. The aluminum wires were at diameters of 0.2, 0.3 and 0.4 mm and 300 mm length. Many parameters can influence the particles produced by EEW. In this work, we examined

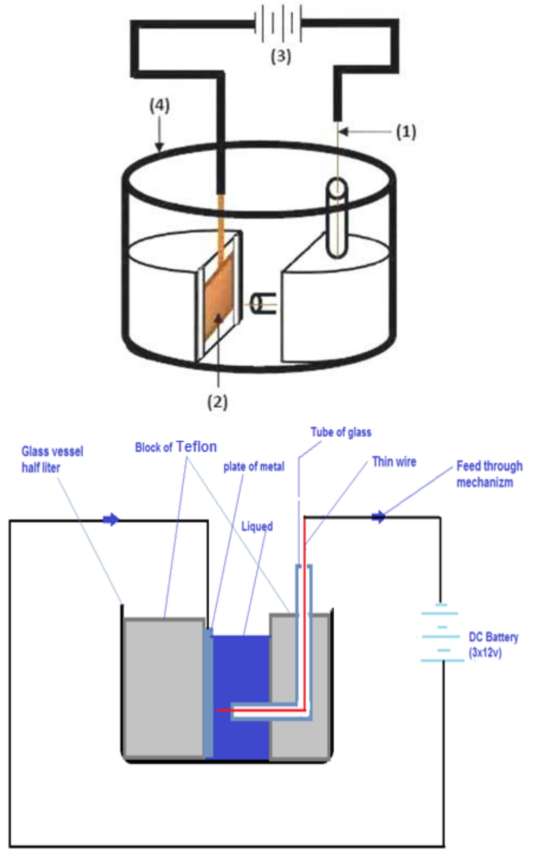


Fig. 1 A schematic diagram of the electro-exploding wire (EEW) set up; (1) thin metal wire, (2) Metal plate, (3) 36 V batteries and (4) glass vessel.

the effects of wire diameter and liquid type such as water, ethylene glycol (polar solvent) and cyclohexane (nonpolar solvent).

The structural features of the samples was studied by X-ray diffraction (XRD),the X-ray measurements have been done according to the (ASTM**)** American Society of Testing Materials cards, using MINIFLEX II Japan device X-ray diffract meter of λ = 1.54 Å from Cu-kα radiation, where a few drops from the nanoparticles suspension were deride on glass substrate for recording X-ray diffraction. The average grain size (G.S.) can be estimated using the Scherrer's formula [17]. The topography of the prepared nanoparticles is studied by TEM and SEM to confirm the nanoparticles shape, size and particle sizedistributions. The TEM type was CM10 pw6020, from Philips-Germany. The test samples were prepared by placing a drop of suspension of interest on a copper mesh coated with an amorphous carbon film. This process was repeated several times. The TEM carbon grids were loaded into the sample. The images were obtained at an accelerating voltage of 60 kV, with maximum magnification of 25000x-920000x. UV-VIS 1800 spectrophotometer was used to measure the absorption spectrum of metallic NPs solution samples prepared at different conditions in the spectrum range 190-1100 nm. All spectra were measured at room-temperature in a quartz cell with 1cm optical path.

3. Results and Discussion

3.1 XRD Study of Aluminum Nanoparticles

XRD was performed for the Aluminum nanoparticles that obtained from exploding Aluminum wires with different diameters (0.2, 0.3 and 0.4 mm), in water media, ethylene glycol and cyclohexane. The diffraction pattern is shown in Figs. 2 to 4 and the results were summarized inTable 1. Part of the solid matrix, was dried and held firm for XRD studies. The indexing process of a powder diffraction pattern was done, and Miller Indices (h k l) to each peak was assigned. All Miller Indices reveal the FCC structure of Aluminum nanoparticles. The peaks were assigned to the diffraction from the 111, 200, 220, and 311 planes of FCC Bulk Aluminum. It observed, in preference, diffraction peaks of Aluminum NPs at crystalline plans 111, 200, 220, 311 and 222. The relative intensities of the lines have, however altered, and showing re-orientation of grains following their production through the EEW method. Diffraction pattern Corresponding to impurities is found to be very low. This indicates that pure Aluminum NPs were synthesized. When comparing the diffraction pattern of Aluminum NPs with bulk Aluminum, the peak positionsof the Aluminum NPs planes were slightly shifted to higher 2θ values.

The average particle size of Al nanoparticles, which were determined using Scherrer's equation, shows that Aluminum nanoparticles produced in ethylene glycol have smaller size compared with that produced in water, and that produced in cyclohexane were smaller than that produced in ethylene glycol at the same conditions, this is because that the three media have different properties. The particle size decreased under fast decreasing the particle size and raising the dispersion stability due to less expansion in the plasma volume. X-ray diffraction pattern for the Aluminum nanoparticles produced in cyclohexane shows explosion conditions, short plasma duration and with high-viscosity surrounding media. High viscosity was diffraction from two planes only with less intensity

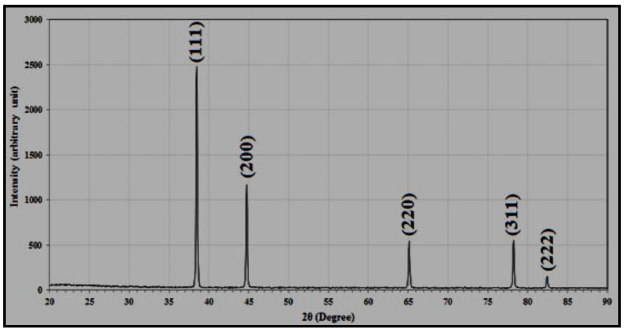


Fig. 2 X-ray diffraction pattern for bulk Aluminum.

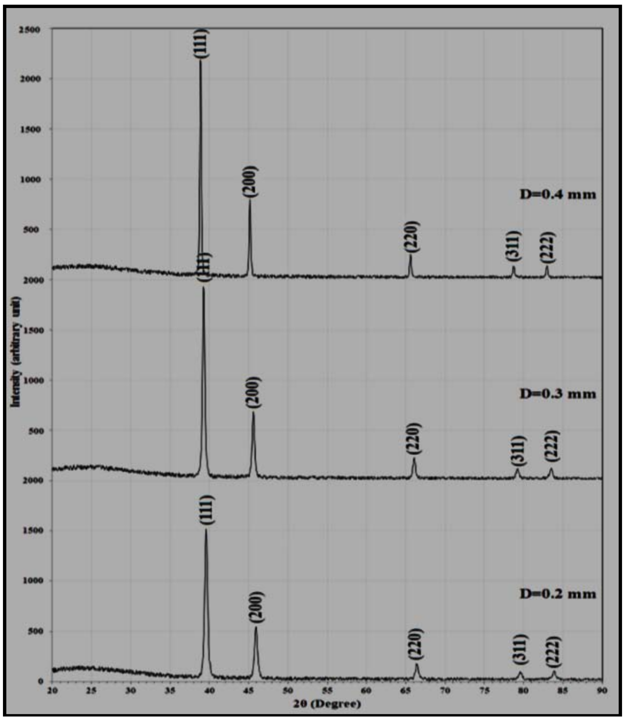


Fig. 3 X-ray diffraction pattern for Aluminum nanoparticles from exploded Al wire with different diameter in water.

Table 1 XRD peaks of aluminum bulk and nanoparticles obtained from exploding aluminum wires with different diameters in water media, ethylene glycol and cyclohexane.

Media	D(mm)	2θ	FWHM	Int.(A.U)	(hkl)	G.S (nm)	Avg,G.S (nm)
Water	0.2	39.583	0.391	1520	(111)	20.3	20.48
		45.927	0.414	525	(200)	19.6	
		66.405	0.437	150	(220)	20.5	
		79.588	0.460	76	(311)	21.2	
		83.891	0.483	75	(222)	20.8	
	0.3	39.272	0.323	1920	(111)	24.6	24.74
		45.594	0.342	665	(200)	23.7	
		66.049	0.361	190	(220)	24.7	
		79.207	0.380	95	(311)	25.6	
		83.484	0.399	95	(222)	25.1	
	0.4	38.872	0.206	2235	(111)	38.5	38.74
		45.166	0.218	782	(200)	37.2	
		65.591	0.230	224	(220)	38.7	
		78.717	0.242	112	(311)	40.0	
		82.959	0.254	112	(222)	39.3	
Ethylene glycol	0.2	39.575	0.504	760	(111)	15.8	15.90
		45.918	0.534	266	(200)	15.2	
		66.396	0.563	76	(220)	15.9	
		79.578	0.593	38	(311)	16.4	
		83.881	0.623	38	(222)	16.2	
	0.3	39.458	0.323	1050	(111)	24.6	24.8
		45.793	0.342	368	(200)	23.8	
		66.262	0.361	105	(220)	24.8	
		79.435	0.380	53	(311)	25.6	
		83.727	0.399	53	(222)	25.2	
	0.4	39.322	0.226	1650	(111)	35.1	35.34
		45.648	0.239	578	(200)	33.9	
		66.106	0.253	165	(220)	35.3	
		79.268	0.266	83	(311)	36.5	
		83.549	0.279	83	(222)	35.9	
Cyclohexane	0.2	39.622	0.536	40	(111)	14.9	14.9
	0.3	39.183	0.425	60	(111)	18.7	18.35
		45.499	0.450	21	(200)	18.0	
	0.4	39.138	0.342	90	(111)	23.2	22.8
		45.451	0.362	32	(200)	22.4	
Bulk Al		38.480	0.150	2500	(111)		
		44.747	0.158	1144	(200)		
		65.142	0.167	520	(220)		
		78.237	0.176	546	(311)		
		82.446	0.185	130	(222)		

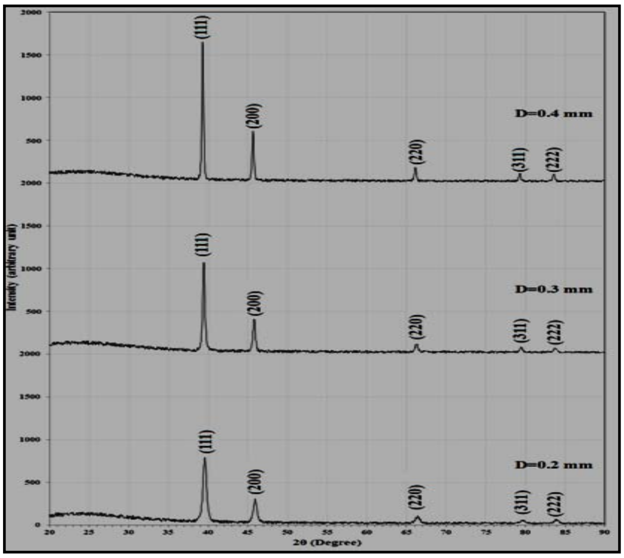


Fig. 4 X-ray diffraction pattern for Aluminum nanoparticles obtain from exploded Al wire with different diameter in ethylene glycol.

than that for bulk Aluminum, that means silver nanoparticles capped by a thick layer of cyclohexane, which preventing the appearance of low intensity peaks. Parameters that can influence the properties of nanoparticles synthesized by EEW include electrical circuit parameters; voltage, the amount of energy deposited in the wire; the properties of the exploding wire (diameter, length); sublimation of the metal; and properties of the liquid, as viscosity, thermal conductivity, polarity. Table 2 shows some of the physical properties of liquids media used in this work.

3.2 UV–Visible Absorption Spectrum of Aluminum Nanoparticles

The UV–Visible absorption spectrum of Al nanoparticles in water ethylene glycol and cyclohexane media are given in Figs. 6 to 8 from the figures there are no characteristic peak in the visible regain. The typical peak at 209, 214 and 231 nm correspond to the characteristic surface plasmon resonance of Al nanoparticles obtain from 0.2 mm, 0.3 mm and 0.4 mm exploding Al wires in water media. It is well known that colloidal Al nanoparticles exhibit absorption at the wavelength from 200 nm to 240 nm due to Mie scattering. The varying intensity of the plasmon resonance depends on the cluster size. In ethylene glycol and cyclohexane it found red shift of the absorbance maximum for Al nanoparticles. The value was located around 250-390 nm.

Table 2 Physical properties for liquids media.

Liquid	**Structure and molecular weight**	**Density g/ml**	**Dielectric constant**	**Dipole moment**	**Viscosity 10^{-3}Pa.S**	**Surface tension 10^{-3}J/ m^2**
Cyclohexane	C_6H_{12} 84.16	0.7739	2	0	0.898	24.4
Ethylene glycol	HOC_2H_4OH 62.07	1.1097	37.7	2.2	16.13	47
Water	H_2O 18.02	0.997	78.39	1.84	0.8905	71.98

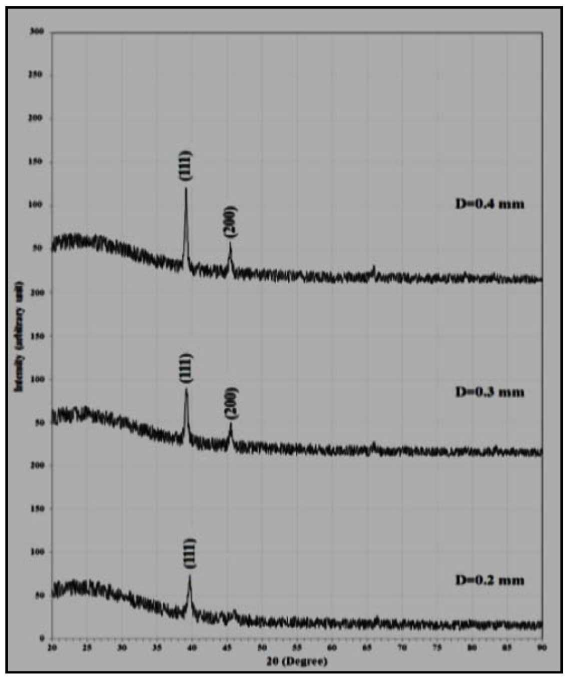


Fig. 5 X-ray diffraction pattern for exploded Al wire with different diameter in cyclohexane media.

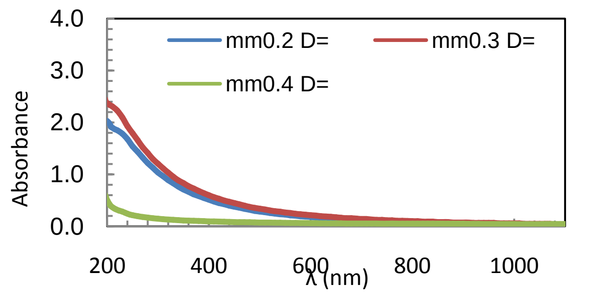


Fig. 6 Absorbance within UV visible for film deposited from Al wire with different diameter in water.

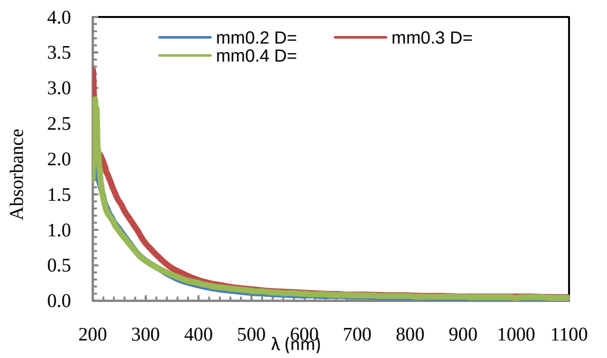


Fig. 7 Absorbance within UV visible for film deposited from Al wire with different diameter in Ethylene glycol.

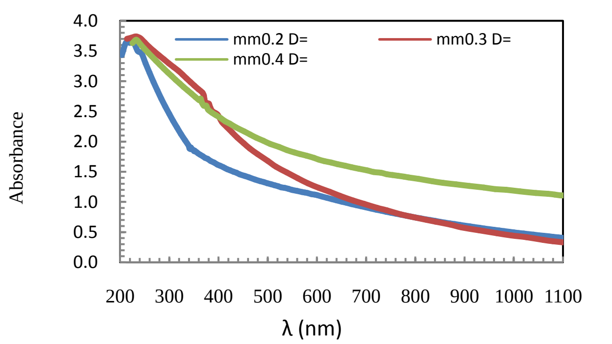
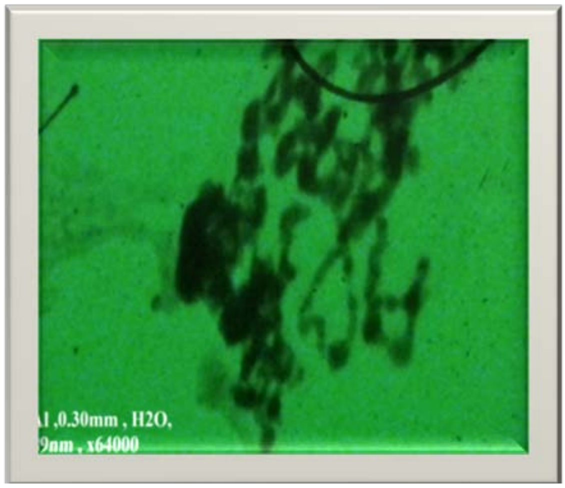


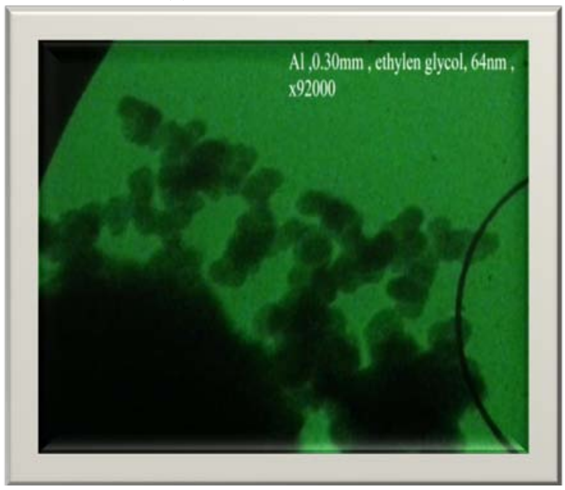
Fig. 8 Absorbance within UV visible for film deposited from Al wire with different diameter in cyclohexane.

3.3 TEM &SEM of Aluminum NPs Synthesized in Liquids Media

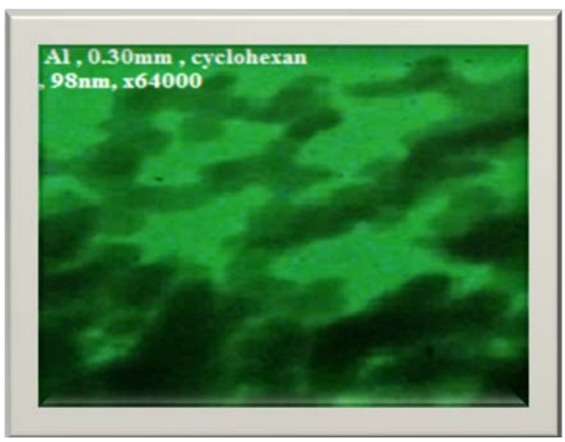
Fundamental study of samples morphology were obtained using scanning electron microscopy (SEM) to observe the external structures of nanoparticles andTransmission Electron Microscope (TEM) to characterize of the texture of the metal nanoparticles. From the images of TEM there are varies size with the range from 64-98 nm, also the particles have a little irregular shapes low agglomerateas shown in Figs. 9 and 10.



(a) Al, 89 nm, x64000



(b) Al, 64 nm, x92000



(c) Al, 98 nm, x64000

Fig. 9 TEM images for synthesized Aluminum NPs (a) in water, (b) ethylene glycol and (c) cyclohexane obtained for 0.3 mm exploded Al wire.

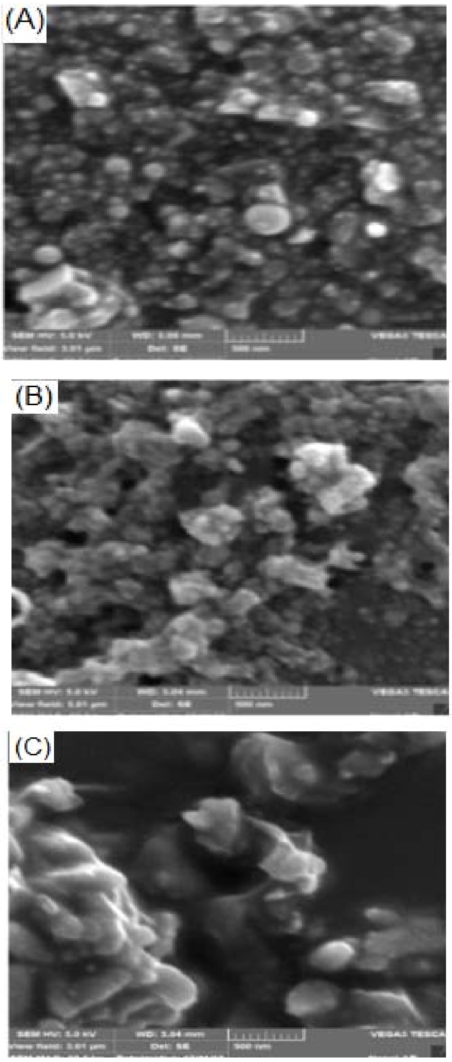


Fig. 10 SEM images of synthesized Aluminum NPs (A) in water, (B) ethylene glycol and (C) cyclohexane obtained from 0.3 mm exploded Al wire.

4. Conclusions

Our measurements confirm that the Aluminum nanoparticles have been generated by EEW technique. Change of the wire surrounding medium in the explosion process presents a simple and flexible technique to modify the properties of nanoparticles. The size of the NPs decreases with the decrease of the metal wire diameter for the three liquids used. For the same wire diameter, the NPs prepared in cyclohexane were smaller than particles prepared in ethylene glycol and water respectively. UV-Visible absorption spectrum of Aluminum nanoparticles showed no SPR absorption peak in the visible region. SEM and TEM images showed that the synthesized NPs have an average particle size less than 100 nm with narrow participle size distribution and having spherical shapes with slight agglomerations.

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