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Structural, Optical and Frequency Dependent Electrical Behaviour of Aluminum Nitride (ALN) Nanopowder

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Abstract**: *Aluminum nitride (AlN) is ceramic material. It has very high thermal and low electrical conductivity. The Variation of Various Electrical Parameters viz. Impedance (Z), Admittance (Y), Dielectric Permittivity (ε'), Relative Loss (ε''), Electrical Conductivity (σ), and Loss Tangent (Tan δ) with frequency Dependence of Aluminum Nitride (AlN) Nano powder were studied. Scanning electron microscopy (SEM); Raman Spectroscopy; and X-ray diffraction (XRD) were used to analyse the surfaces and structures of aluminum nirtride nanopowder. It has been found that the particle size is of 36.15 nm and the crystallographic structure is amorphous. The surface morphology of the studied compound has been investigated by Scanning Election Microscopy (SEM) indicating the particles are in nanosize and characteristic range of diameters are in nanoscale. The electrical studies of the studied compound have been examined in order to acquire the electrical parameters (mainly dielectric permittivity, loss, conductivity, loss-tangent, impedance, and admittance). Small rise in the conductivity (with frequency dependent) has been observed due to the decrease in the particle size of the material.it is also observed that the relative permittivity (ε'), relative loss (ε'') and dissipation factor (Tan δ) decreases with increase in frequency. The Raman shift variation with the intensity which shows the peaks of the compound are obtained at 506 cm^{-1}, 615 cm^{-1} 656 cm^{-1}, 873 cm^{-1}, 882 cm^{-1}, 949 cm^{-1}, and 974 cm^{-1}using laser at 785 nm.***

Keywords ***: AlN, XRD, SEM, Raman spectroscopy, relative loss and Electrical Conductivity.***

I. INTRODUCTION

Aluminum nitride ceramics is an very useful material for electronics manufacturing of electronic devices due to high thermal stability and very low electrical conductivity and the thermal expansion coefficient similar to silicon [1].

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High M.P., good thermal strength and corrosion resistance of molten aluminum and cryolyte ensure a important of AlN in other fields. AlN finds importance in producing composite materials [2-3]. AlN also has optical characteristics [4]. The properties of AlN are strongly influenced by chemical purity, density and structure [5].Thermal management has always been a major concern in the design of high frequency and power electronic devices. In order to avoid the breakdown of electronic devices, composites materials used in these devices should have high thermal strength and electrical insulator properties. Normally, high thermal conductive performance has been obtained by adding fillers due to the thermal conductive chains or networks produced by the fillers [6–10]. An outstanding challenge to enable such applications has been a thorough understanding of the Aluminum Nitride (AlN) Nano powder's electrical response with variation of frequencies. However, values of the required parameters are often an open question as they could be significantly affected by the material, size, and measuring device fabrication process [11]. The following study concern with the change in electrical parameters such as relative permittivity (ε'), relative loss (ε''), dissipation factor (Tan δ) and conductivity with change in frequency.

II. EXPERIMENTAL ANALYSIS

The X-ray diffraction of Aluminum Nitride (AlN) Nano powder was conducted on a Philips Analytical XPERT-3 diffractometer using a Cu Kα radiation (λ = 1.54056 A°) with a MINIPROP detector and operating at 40 kV and 30 mA. X-ray diffraction patterns were recorded between 2θ = 5◦ and 109◦ with a step of 0.013◦ and a scan step time of 18.87 s by step. The crystallographic data of the resulting Aluminum Nitride (AlN) nanopowder were collected by using the BBHD_MPPS_1D.xrdmp, Identifier Diffraction software. Surface morphologies of the specimens were observed with a scanning electron microscope (SEM, JEOL JEC3000FC) in which coating time is 60 sec operating from 1kv to 5kv and using 70% inert gas. In the Raman spectroscopy the experiment time is 30sec, laser power is used 0.5% and the range is selected from 100-2000 Counts using RENISHAW In Via Raman Microscope model of Raman spectroscopy.
The dielectric measurements for the samples have been carried out with the dielectric cells in the form of parallel-plate capacitor.

For unaligned, the dielectric cell has been prepared using indium tin oxide-coated glass plates, having surface resistance less than 1.0-1.5 ΩSq^{-1} The material has been filled in the cell at room temperature with the Nova Impedance Analyser Alpha A Type.

The measurement of conductivity is based upon the formula given as following R = (ρd) / A

R is proportional to the separation (d) between the electrodes, resistivity (ρ) of the material and inversely proportional to the cross-sectional area of the sample (A) Conductance (G) = 1 / R = Aσ / d (conductivity σ = 1/ρ). Using $C_A = A\,\varepsilon_0 / d$. Here, $\sigma = G\,\varepsilon_0 / C_A = \varepsilon_0 / RC_A$

The tan delta or dissipation factor of the investigated compound has been determined in the following way Dissipation factor or Tan δ = 1/2πfCR.

The Various Electrical Parameters viz. Impedance (Z), Admittance (Y), Dielectric Permittivity (ε'), Dielectric Loss (ε"), Electrical Conductivity (σ), and Loss Tangent (Tan δ) of Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC.

III. Result and Discussion

a. Xrd Results

TABLE 1: XRD results of studied sample, Pos. [°2θ], Height [cts], FWHM Left [°2θ] d-spacing [Å], and d-spacing [Å] of Aluminum Nitride (AlN) nanopowder at Room Temperature.

Pos. [°2θ]	Height [cts]	FWHM Left [°2θ]	d-spacing [Å]	Rel. Int. [%]
33.2025	2133.23	0.2814	2.69833	100.00
36.0069	1605.47	0.2303	2.49434	75.26
37.9023	1650.25	0.2047	2.37386	77.36
44.5787	183.17	0.2047	2.03261	8.59
49.8112	555.89	0.3582	1.83066	26.06
59.3012	765.64	0.2814	1.55836	35.89
66.0273	648.95	0.5117	1.41498	30.42
71.3658	457.44	0.3070	1.32168	21.44
72.6054	192.39	0.4093	1.30215	9.02
94.8182	133.89	0.8187	1.04718	6.28
101.0770	92.47	0.8187	0.99856	4.33

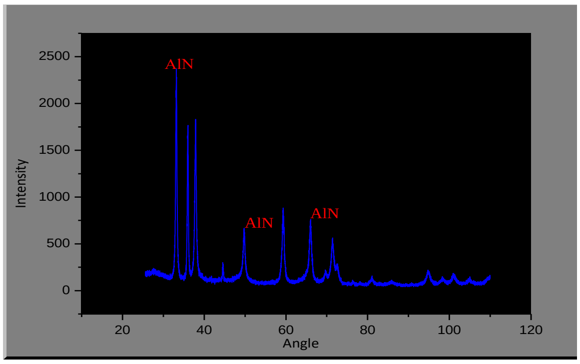

Figure 1. The diffractogram of AlN nanoparticle.

The figure 1 depicts the X-ray diffraction (Cu Kα radiation) spectrum of the Aluminum Nitride (AlN) nanopowder. The synthesized magnetic nanoparticles oxide shows good nanoparticles structure and are stable in hydrocarbon solvents against air oxidation. Figure 1 show the XRD patterns of Aluminum Nitride (AlN) nanopowder at room temperature. The nano-sized Aluminum Nitride (AlN) nanopowder is in crystalline structure. Its average particle size was 36.15 nm. That calculated through the Scherrer's formula D=kλ/βcosθ[12]

b. SEM Results

Scanning electron microscopy (SEM) micrograph of agglomerated nanocrystalline iron nickel oxide particles produced. Scanning electron microscopy (SEM) images of Aluminum Nitride (AlN) nanopowder. (Figure 2 & 3) indicating the varies from 100-200 nm size, agglomeration of particles, with diameters ranging from nanoscale. The morphology of the Aluminum Nitride (AlN) nanopowder was characterized by SEM images as shown in Figure 2 & 3. From images results, we can observe a large quantity of uniform nanoparticles (NPs) with average particle size of nanorange.

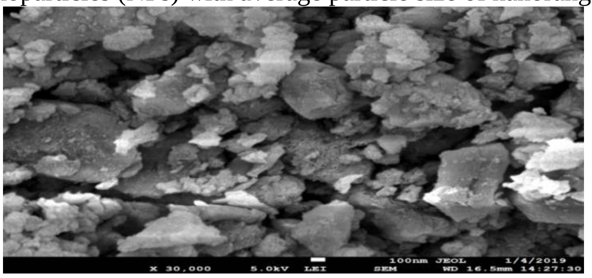

Figure 2. SEM image of the Aluminum Nitride (AlN) nanopowder.

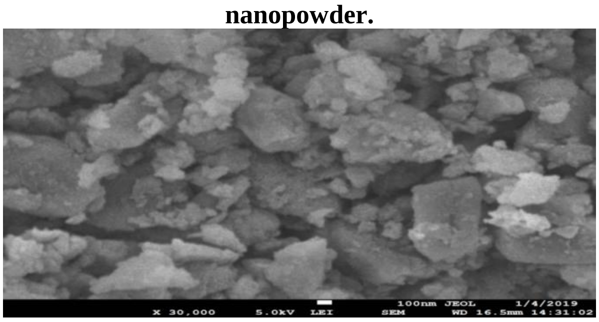

Figure 3. SEM image of the Aluminum Nitride (AlN) nanopowder.

c. Raman Results

In the Raman spectroscopy the experiment time is 30sec, laser power is used 0.5% and the range is selected from 100-2000. The raman shifts peaks is observed 506 cm^{-1}, 615 cm^{-1} 656 cm^{-1}, 873 cm^{-1}, 882 cm^{-1}, 949 cm^{-1} and 974 using laser at 785 nm. In this study of Aluminum Nitride (AlN) nanopowder, there is no significant change in the peak position and intensity.

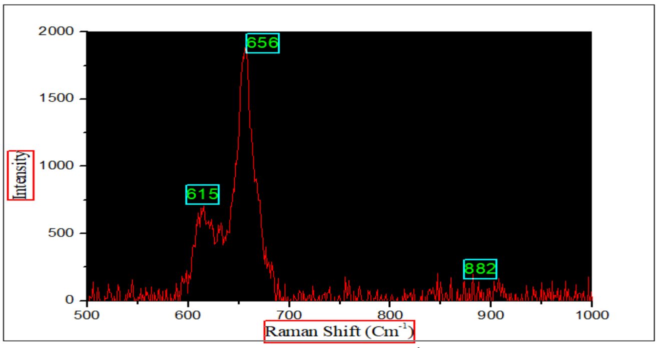

Figure 4: Variation of raman shift (cm^{-1}) vs. intensity of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature.

Table 2. Previously Reported Raman Modes of AIN Mode symmetry.

Frequency (cm^{-1})	Reference
665	**13**
303	**16**
426	**16**
667	**13**
659	**14**
659	**15**
667	**13**
672	**14**
671	**15**
614	**16**
910	**13**
897	**14**
888	**15**
663	**16**
910	**13**
912	**14**
895	**15**
821	**16**

The Raman shifts are consistent with those of Aluminum Nitride (AlN) nanopowder nanoparticles which are good agreement with XRD results.

d. Electrical Study

Frequency (Hz)	Z (Ω)	Y $(\Omega)^{-1}$	ε'	ε''	σ ($S\text{-}m^{-1}$)	Tan δ
1 kHz	5.59×10^{7}	1.79×10^{-8}	1.09	0.44	2.51×10^{-8}	0.043
10 kHz	1.95×10^{7}	5.13×10^{-8}	0.84	0.12	7.21×10^{-8}	0.15
100 kHz	5.49×10^{6}	1.82×10^{-7}	0.76	0.046	2.56×10^{-7}	0.059
1 MHz	1.40×10^{6}	7.2×10^{-7}	0.73	0.017	1.00×10^{-6}	0.023
10 MHz	-2.87×10^{4}	-3.48×10^{-5}	0.72	-0.091	-4.98×10^{-5}	-0.12

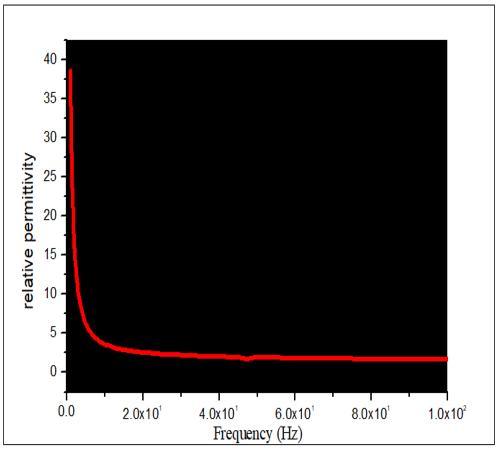

Figure 5: Variation of frequency (Hz) vs. relative permittivity (ε') of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC.

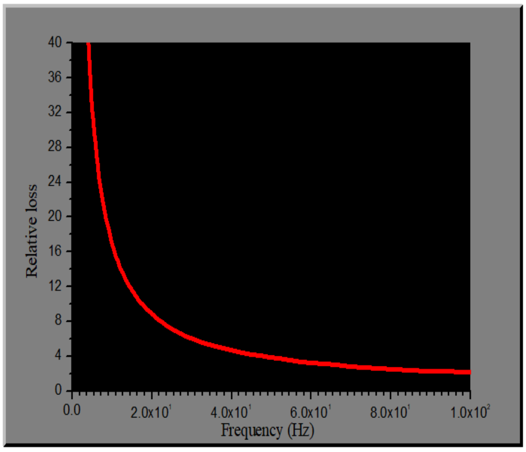

Figure 6: Variation of frequency (Hz) vs. relative loss (□'') of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC.

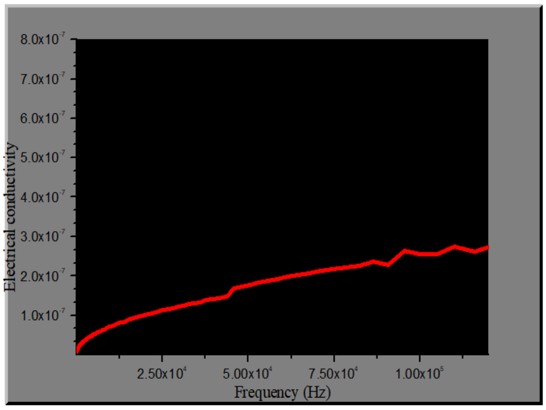

Figure 7: Variation of frequency (Hz) vs. electrical conductivity (□) of the Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC.

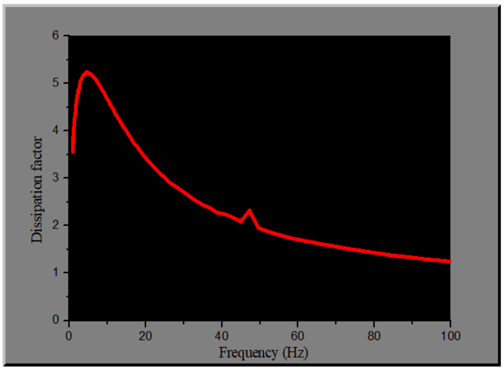

Figure 8: Variation of frequency (Hz) vs. dissipation factor (Tan □) of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC.

The figure 5 represents that the values of relative permittivity (ε') of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC at 10 KHz, 100 KHz, 1MHz and100 MHz are 0.84, 0.76, 0.73 and 0.72 respectively. Thus as frequency increases the relative permittivity (ε') decreases continuously and become minimum at very high frequencies.

The figure 6 represents the values of relative loss (□϶϶) of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC at 10 KHz, 100 KHz, 1MHz and100 MHz are 0.12, 0.046, 0.017 and -0.091 respectively. Thus as frequency increases relative loss ((ε**''**) decreases continuously and becomes minimum at very low high values of frequency.

The figure 7 represents that that the values of electrical conductivity (σ) of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC at 10 KHz, 100 KHz, 1MHz and100 MHz are 7.21×10^{-8}, 2.56×10^{-7}, 1.0×10^{-6} and -4.89×10^{-5} □S-m^{-1}) respectively. Thus as frequency increases electrical conductivity (σ) also increases continuously and becomes negative at very high frequency.

The figure 8 represents that the values of dissipation factor (Tan δ) of the investigated sample Aluminum Nitride (AlN) nanopowder at Room Temperature 32.1 ºC at 10 KHz, 100 KHz, 1MHz and100 MHz are 0.15, 0.059, 0.23 and -0.12 respectively. . Thus as frequency increases first the dissipation factor (Tan δ) increases up to a peak value and further on increasing the frequency it start to decrease and at very high frequencies the dissipation factor (Tan δ) becomes minimum.

IV. CONCLUSION

In this research it has described that at room temperature the structural and electrical study of Aluminum Nitride (AlN) nanopowder has done. It is found that the Aluminum Nitride (AlN) nanopowder with in nanosize, shape distribution agglomeration of particles, with diameters in nanoscale has been characterized by SEM, XRD and RAMAN SPECTROSCOPY. In addition, it is also observed that the relative permittivity (ε'), relative loss (ε'') and dissipation factor (Tan δ) decreases with increase in frequency.

Here small rise in the conductivity (with frequency dependent) has been observed due to the decrease in the particle size of the material (nanoscale). The Raman shift variation with the intensity which shows of studied compound has been analysed by Raman Spectroscopy.in which peaks are obtained observed at 506 cm^{-1}, 615 cm^{-1} 656 cm^{-1}, 873 cm^{-1}, 882 cm^{-1}, 949 cm^{-1}, and 974 cm^{-1}using laser at 785 nm.

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