GROWTH AND CHARACTERIZATION OF SODIUM PENTA FLUORO ANTIMONATE SINGLE CRYSTALS

M.S.Anula[1], C. Besky Job[2]*

ABSTRACT

An inorganic material Sodium PentaFluoroAntimonate (Na_2SbF_5) single crystal, have been grown by slow evaporation growth technique.Single crystal X-ray diffraction (XRD)andpowder X-ray diffractionstudies shows that the grown crystal belongs to the orthorhombic system with the non-centrosymmetric space group $P2_12_12_1$. The FTIR spectrum is used to analyze the functional groups present in the grown crystal. Energy dispersive X-ray analysis (EDAX) is used to find the elemental composition of the grown Sodium PentaFluoroAntimonate single crystal.The optical properties of the grown crystal were analyzed by UV-Vis studies. The photoluminescence property of the grown crystal has been analyzed. The thermal properties of the grown crystal have been studied by using TG/DTA studies. The dielectric studies were analyzed by using the parallel plate capacitor method. The Mechanical property of grown crystals studied using microhardness studies.The impedance spectroscopic studies were carried out on the grown crystal from 100 Hz to1 MHz range at room temperature. The Nyquist plot of the grown crystal exhibited the presence of one semi-circle.We can also analyzed by effective separation efficiency of photo induced electron hole pairs and a faster interfacial charge transfer.The nonlinear optical properties of the grown Sodium PentaFluoroAntimonatecrystal were measured using the Z-scan technique. The grown Sodium PentaFluoroAntimonatesingle crystals optical limiting threshold values were analyzed.

Keywords: Crystal growth, optical material, micro hardness, FTIR, UV, orthorhombic, XRD, dielectric loss, dielectric constant, impedance ,NSF, Nyquistplot, NLO.

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1. **Introduction**

The inorganic single crystals have good applications in semiconductors, solid-state lasers, optics, piezoelectric materials, photosensitive materials, optoelectronic switching, electro-optic modulation, laser frequency conversion, optical logic gates in telecommunications, laser radiation protection microelectronics, computer microelectronics and computer industries. In recent years' crystal engineering remains the most remarkable and quickly developing field. In worldwide the scientists are interesting for inorganic materials because the materials have wide transparency and commercially feasible. The slow evaporation single crystal growth method has significant attention among the many synthesized processes to grow NLO crystals. Trivalent antimony complexes comprise a large class of inorganic compounds, many of which have peculiar electro-physical [1, 2] optical [3, 4] and other prototypical [5, 6] characteristics. Several fluoroantimonates have high ionic conductivities. These compounds are of great interest because, according to the theory [7, 8], the liable cations Na^{2+} in a crystal lattice are likely to have conductivity values that are higher than those of the cations of heavy alkali metals. The inorganic materials sodium fluoroantimonate including $(Na)_2SbF_5$, $(Na)Sb_3F_{10}$ and $(Na)_2Sb_4F_{13}$ single crystals are grown and their properties are analyzed [9-18].The inorganic Sodium PentaFluoroAntimonate$(Na)_2SbF_5$single crystals has been successfully grown and characterized by the single crystal XRD, Powder XRD, FTIR, EDAX,UV-Vis, Photoluminescence, TG/DTA, Dielectric, Impedance, micro hardness and NLO studies.

2. Experimental Studies

The commercially available AR grade inorganic materials, hydrofluoric acid,sodiumfluorideand antimony trioxide were purchased from Sigma Aldrich with 99% purity. The material was synthesized by using a molar ratio (3:2:0.5).The governing chemical equation is,

$$3HF + 2NaF + 0.5Sb_2O_3 \longrightarrow (Na)_2 Sb F_5 + 1.5 H_2O$$

The calculated amount of reactants was stirred for 6 hours indouble distilled water and kept for crystallization under room temperature. The transparent good quality Sodium PentaFluoroAntimonate single crystals were grown. The photograph of the grown crystalswas shown in Fig.1.

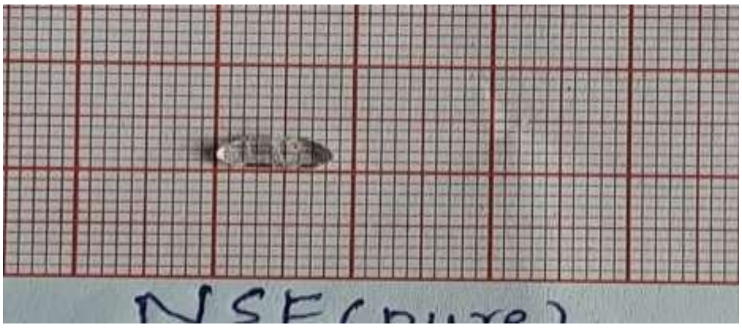


Fig.1 Photograph of $(Na)_2SbF_5$single crystal

3. Results and Discussion

3.1 X-ray diffraction studies

The grown crystals lattice parameters were observed usingsingle crystal X-ray diffraction investigation. It was carried out using the XPERT-PRO diffractometer. The result revealsthat, the grown $(Na)_2SbF_5$single crystal belongs toorthorhombic crystal system with non-centrosymmetricspace group $P2_12_12_1$. The obtained results are well agreement with the reported literature[5] and which is shown in Table 1.

Table 1 : Unit cell parameters

Unit cell Parameters	Literature study	Present Study $(Na)_2SbF_5$
a (A^0)	5.453	5.44(3)
b(A^0)	8.006	8.011(3)
c(A^0)	11.133	11.194
α(^{0})	90	90
β(^{0})	90	90
γ(^{0})	90	90
Volume(A^3)	486.1	486.2(3)
System	Orthorhombic	Orthorhombic
Space group	$P2_12_12_1$	$P2_12_12_1$

3.2. Powder XRD Studies

The powder X-ray diffraction pattern of the grow ccrystal has been carried out using Bruker D8 Advance Powder X-Ray Diffractometer with CuKα Radiation(λ=1.5418A^0). It was done in 0.2s^{-1}scanning rate and in the range of (10 to 80^0). The PXRD pattern of the grown Sodium Penta Fluoro Antimonate is shown in Fig.1. The obtained powder X-ray diffraction pattern was good agreement with the JCPDS file(27-0733).The obtained high-intensity Bragg's peaks show that the grown $(Na)_2SbF_5$single crystal have good crystalline nature.

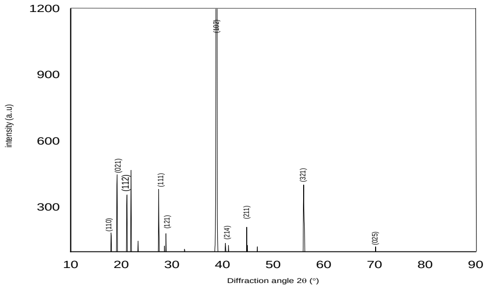


Fig. 1. Powder XRD spectrum forNa_2SbF_5crystal

3.2 Fourier Transform Infrared Analysis

Fourier Transform Infrared (FTIR) analysis is used to identify the functional groups present in the grown crystal. Perkin Elmer FTIR spectrometer has been used to record the FTIR spectrum using the KBr technique.Fig.2 shows the FTIR spectrum of Na_2SbF_5 crystal in the region of 4000 cm^{-1} to 400 cm^{-1}. The O-H stretching vibration causes a strong absorption band at wavelengths of 3429 cm^{-1} and 2922 cm^{-1}. The Sb-O stretching vibration observed at 1065cm^{-1}. The observed peak at 735 cm^{-1} shows Na-F stretching vibration. Na-Sb vibration observed at 421 cm^{-1}.The obtained FTIR bands of the grown crystal are indicated in Table 2.

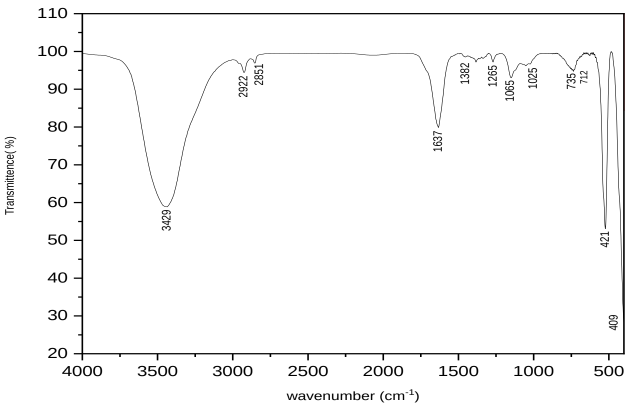


Fig 2a. FTIR spectrum of Na_2SbF_5 single crystals

Table .2

Wave Number(cm^{-1}) (Reference range)	FTIR	Functional group	Assignment
3500-3200	3429	O-H	Symmetric stretching
2300-1675	1637	O-H	bending
1135-1061	1026	Sb-O	Stretching
819-715	712	Sb-O	Symmetric stretching
530-421	525	Sb-F	Symmetric stretching
452-401	421	Na-Sb	Symmetric stretching

3 Energy Dispersive Analysis (EDAX)

The quantitative analysis of grown crystal was analyzed using Elemental Dispersive Analysis by X-ray (EDAX). A portion of the incident electrons from an electron beam excite the specimen's atoms, which release X-rays when they return to their ground state. Since the energy of these X-rays is directly correlated with the atomic number of the excited elements, the electron microscopes elemental analysis starts with their detection [26].The EDAX spectrum of the grown SodiumPentaFluoroAntimonatecrystal was shown in Fig.3. The result shows that the grown crystal contains the elements Na, Sb, and F. The elemental content of the grown crystal as measured by Atomic (%) and the Weight (%) are shown in Table3.

Table 3:

Element	Line Type	Weight(%)	Atomic(%)
F	K-Series	43.35	49.06
Na	K-Series	53.95	50.46
Sb	L-Series	2.7	0.48
Total		100	100

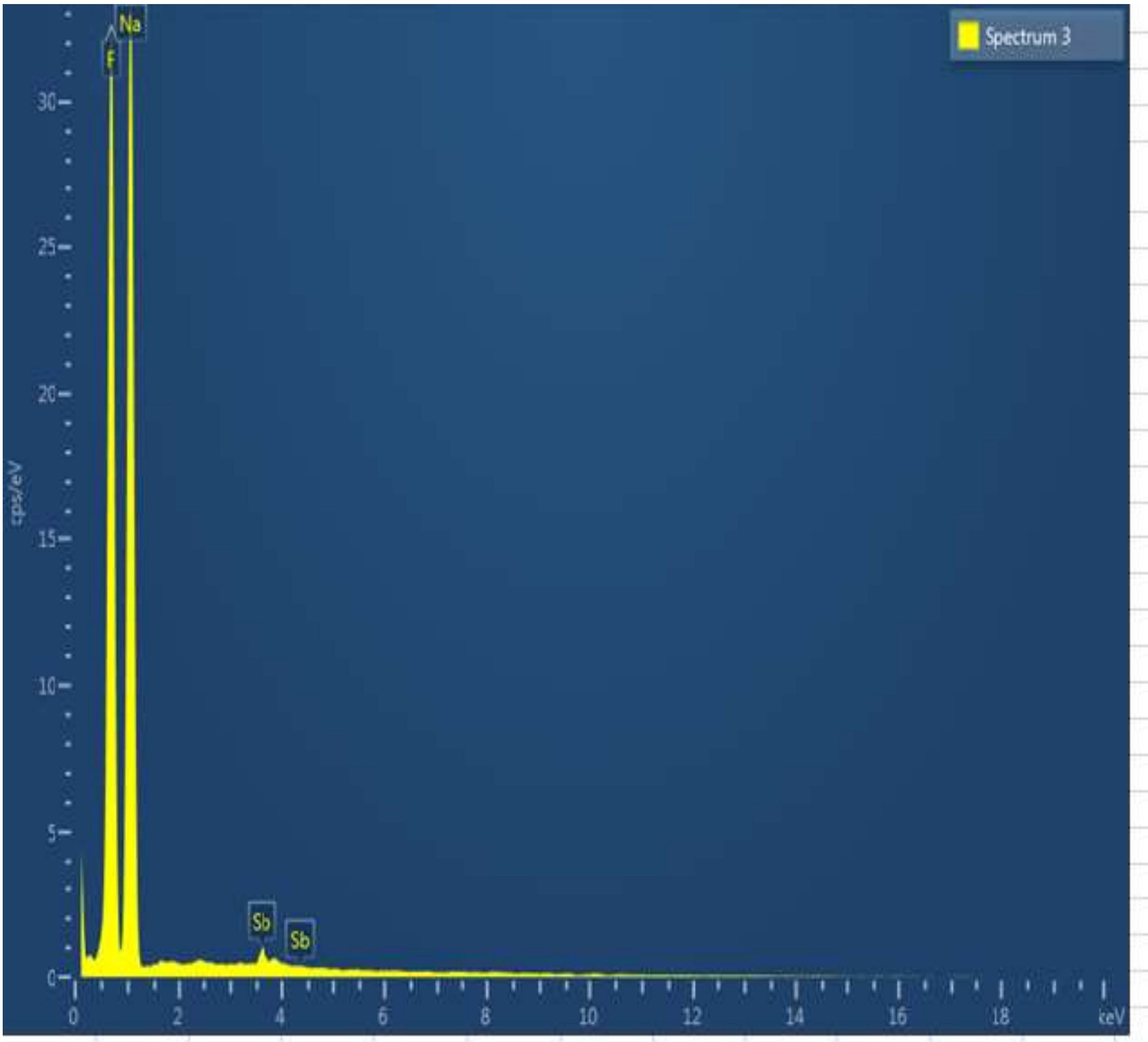


Fig. 3. EDAX spectrum Na_2SbF_5 single crystal

3.4. UV-Vis-NIR spectral Analysis

UV-Vis-NIR spectral analysis is used to investigate the optical transparency of single crystals. The UV- visible analysis of the grown crystal was carried out by Perkin Elmer Lambda 35 UV-Vis Nis spectrometer in the Wavelength region of 100-1100nm. UV- Vis spectral analysis yields prominent structural information since the absorption of UV light holds the endorsement of the electrons in p and s orbital's from the ground state to higher energy states [23,24].The transmission spectrum of grown crystal is shown in Fig.4a. The cut off wavelength of grown crystal was observed around 230 nm. T

he high transmittance value falls in between 200 and 1000 nm confirm the grown crystal . The crystals reveal excellent transmittance in the whole visible region. The lower cut-off frequency with good transparency yields these materials for photonic applications [26].

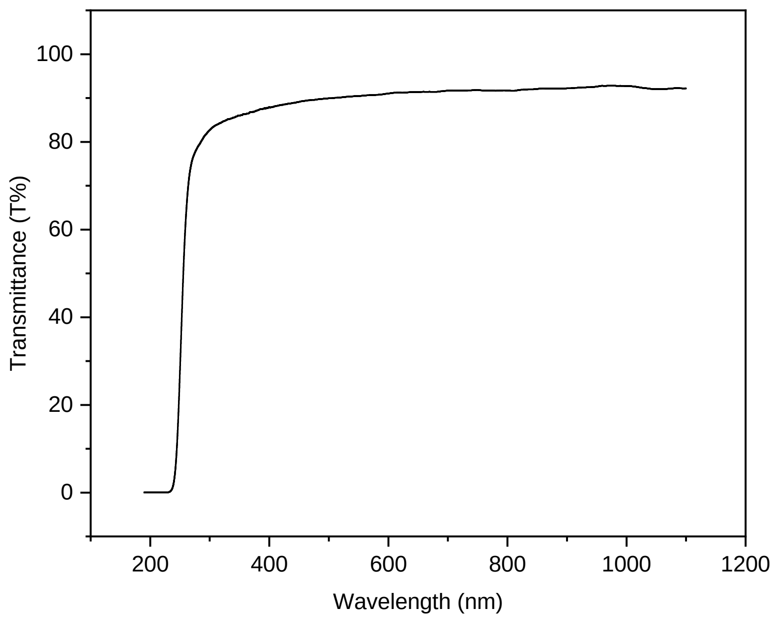


Fig .4a. Optical transmission spectrum of Na_2SbF_5single crystal

To investigate the band structure of a material a linear absorption coefficient is required. The optical absorption coefficient(α) can be determined using the following equation

$$\alpha = [2.303\log(1/T)]/d$$

Where T is the transmittance and d is the thickness of the crystal. linear absorption coefficient versus wavelength for Na_2SbF_5 crystal. The result indicates that the absorption coefficient sample is large at the fundamental absorption.

Tauc'srelation is connecting the absorption coefficient (α) and photon energy(hν), and it is given by

$$(\alpha h\nu)^2 = A(h\nu - Eg)$$

Where E_g is the optical band gap,and A is a constant, the Tauc's plot is drawn between$(\alpha h\nu)^2$ and by hν, and it is shown in fig. 4b. From the figure it is noticed that the optical band gap the grown Na_2SbF_5 crystal is 5.3eV.The large band gaps of grown crystal has less imperfection [24] and have effective application inhigh efficiency optoelectronic devices, high-power and high frequency electronic devices ,ultra-high voltage power electronics devices[20]

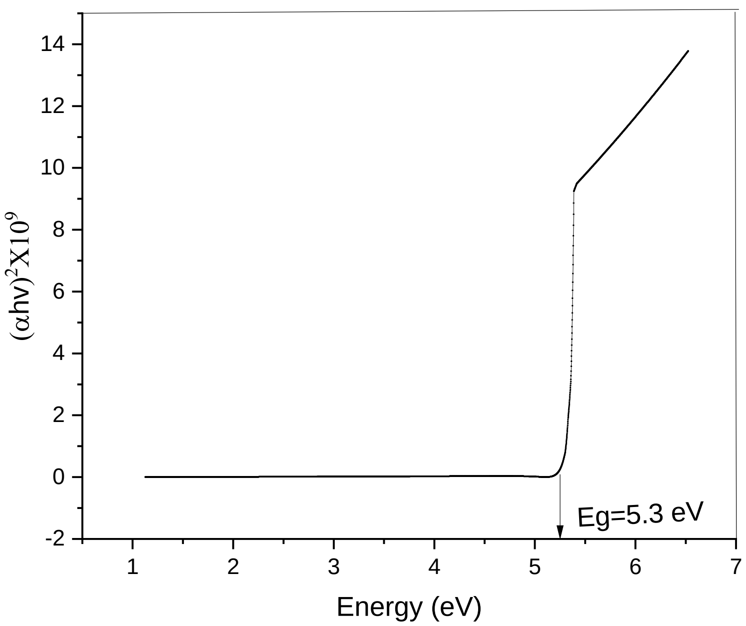


Fig .4c.Tauc's plot for Na_2SbF_5single crystal

Studying optical characteristics of the grown crystal,the extinction coefficients isessential for evaluating whether the grown crystalis suitable for optoelectronic applications [20]. The extinction coefficient (K) is related to the absorption coefficient (α) and wavelength (λ) [22]

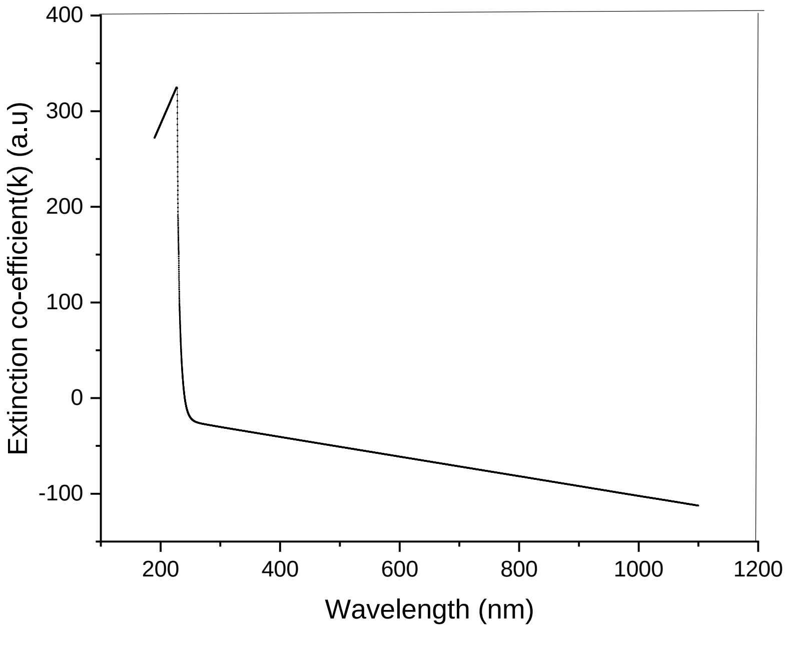


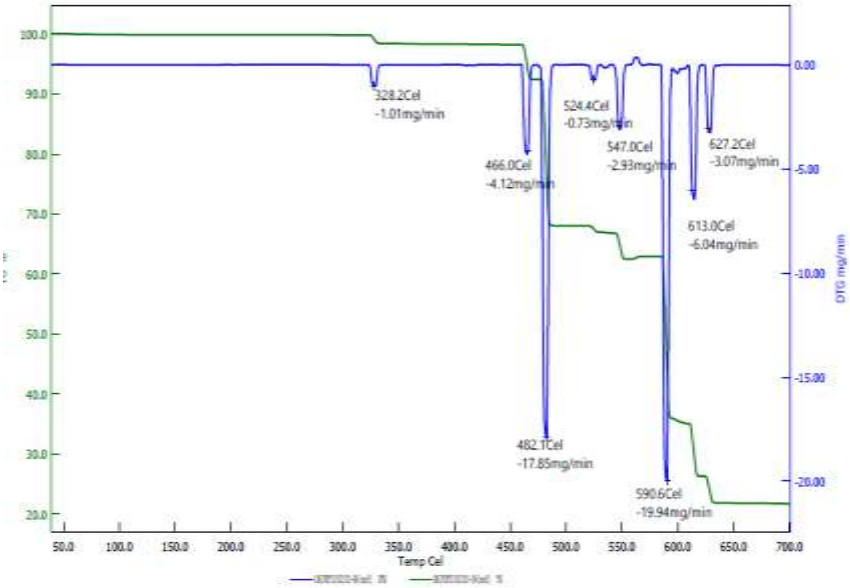
Fig .4c. Variation of Extinction coefficient (K) as a function of Wavelength Na_2SbF_5single crystal

The extinction coefficient (K) measures the damping of light as it passes into the grow crystal. It was determined using the relation

$$K = \frac{\alpha\lambda}{4\pi.} \text{---} (4)$$

Where α linear absorption coefficient and λ the wavelength of light. The wavelength dependence of the extinction coefficient (K) for Na_2SbF_5crystal is presented in fig (4c). Theextinction coefficient (K) is found to be low of the order 10^{-5} for the sample, and it increases with increases of wavelength in the visible region. At UV cut –off wavelength region extinction coefficient (K) of Na_2SbF_5 crystal is observed to be maximum. The high transmittance, low absorbance, and low extinction coefficient (K) of the sample indicate that Na_2SbF_5crystal is suitable for optoelectronic application.

3.5. THERMAL ANALYSIS



Thermogravimetric analysis of the Na_2SbF_5 crystal was carried as a function of weight loss versus temperature using a NETZSCH-STA 449 F3 JUPITER model thermal analyzer. TG/DTA thermal curves for sodium pentafluro antimonite crystal were recorded using TG/DTA thermal analysis in the temperature range 0-700^{0}C and it is shown in the Fig.5. It is clear from the TG that the sample is thermally stable up to 328.2^{0}C. The sample undergoes endothermic transition at 346^{0}C and it corresponds to melting point of the sample. At this temperature, there is a slight weight loss of about 5 weight % and it may be due to the absorbed water molecules. It may be noted here that the endothermic transition at 482^0 C is not decomposition point because there is no heavy weight loss of the sample. The sharp endothermic peak shows the good crystalline perfection of the sample. When the temperature is increased above the melting point, there is a gradual and significant weight loss(75%) occurs in the range of temperature 450- 650^0 C and is due to the decomposition and the release of gaseous particles such as fluorine Sodium and Antimony from the lattice of the crystal. The curve shows that the melting point is 590.6 ^{0}C.

3.6. DIELECTRIC STUDIES

One of the fundamental electrical characteristics that provide information about the distribution of the electric field inside a solid is the study of dielectric response in crystals.It provides the information about different properties like transport phenomena, lattice dynamics, intrinsic aspect of atoms, ions, bonding and their polarization mechanism. The dielectric measurement was carried out by the conventional parallel plate capacitor method using an Agilent 4284ALCR meter. The electrical characteristics, like activation energy, ac conductivity, dielectric loss, and dielectric constant, were computed at various frequencies and temperatures. The highly transparent and flawless crystals are chosen for the dielectric measurements. The Fig. 6(a) and 6(b) depicts the dielectric constant and dielectric loss variation of the grown crystal. The relationship used to compute the dielectric constant is,

$$\varepsilon_r = \frac{(Cd)}{A\varepsilon_0}$$

Where C represents capacitance, A refer area of cross section, ε_0 is permittivity of free space, d is the thickness of crystal. The variation of dielectric **c**onstant on various frequencies at different temperature is shown in fig 6a. At lower frequencies dielectric constant is high and decreases gradually at higher frequencies. The dielectric exchange of ions gives local displacement of electron in the direction of the applied field which in turn give rise to polarization[21]. After a point the space charge cannot sustain at low frequencies hence dielectric constantstart to decrease.

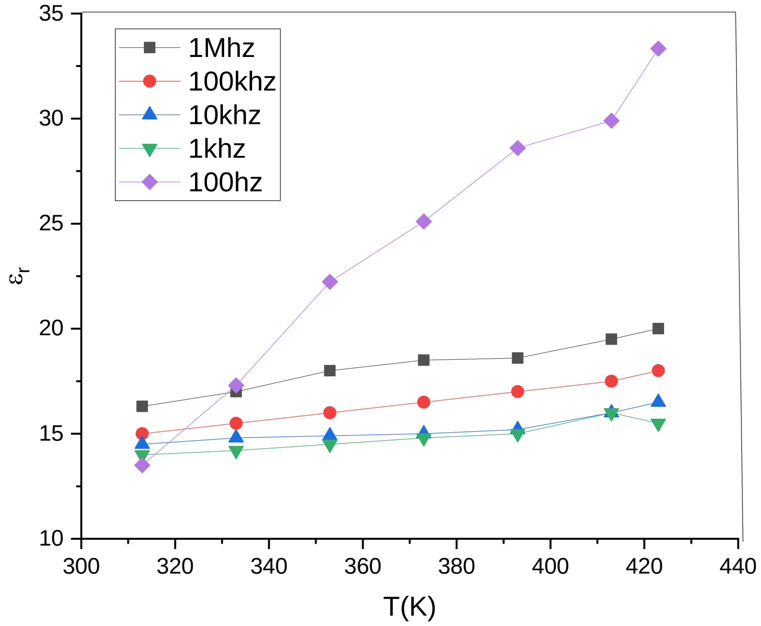


Fig. 6a. Variation of Dielectric constant as a function of frequency

$$\sigma_{ac} = \varepsilon_0 \varepsilon_r \omega \tan \delta$$
$$d = \tan \delta$$

$$\omega = 2\Pi f$$

where σ_{ac} is the AC electrical conductivity, ε_0 the permittivity of free space 8.85 x10^{-12} C^2N^{-1} m^{-2}, ω is the angular frequency and ε_r is the relative permittivity for medium.

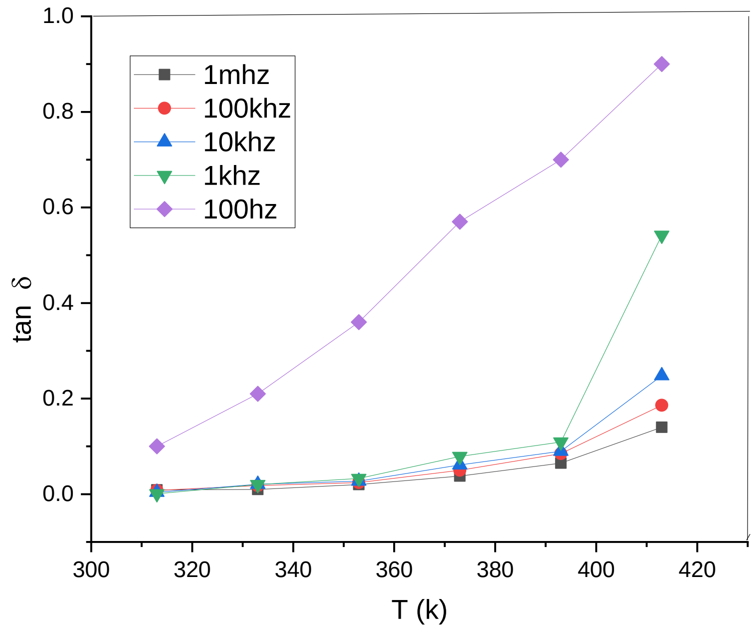


Fig 6b. Variation of Dielectric loss as a function of frequency for Na_2SbF_5 single crystal.

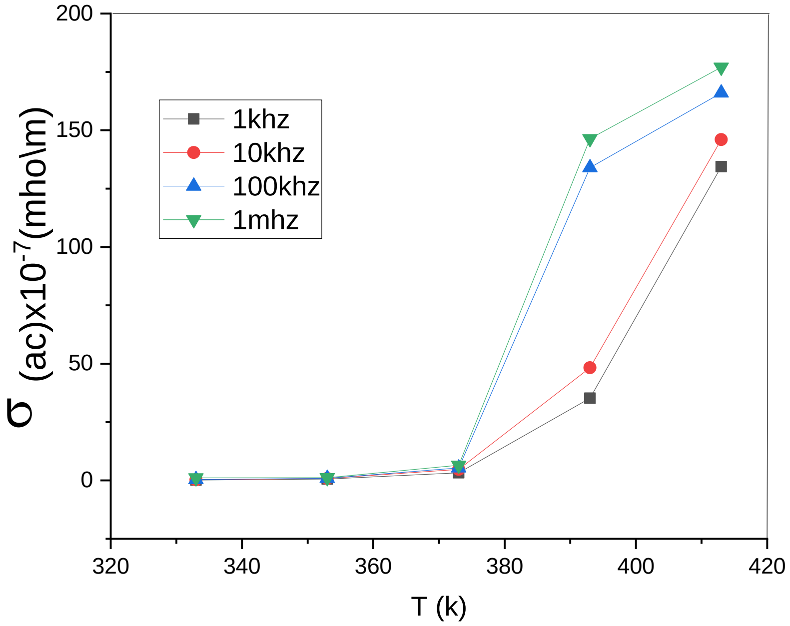


Fig .6c.$\sigma_{(ac)}$versus temperature of Na_2SbF_5 single crystal.

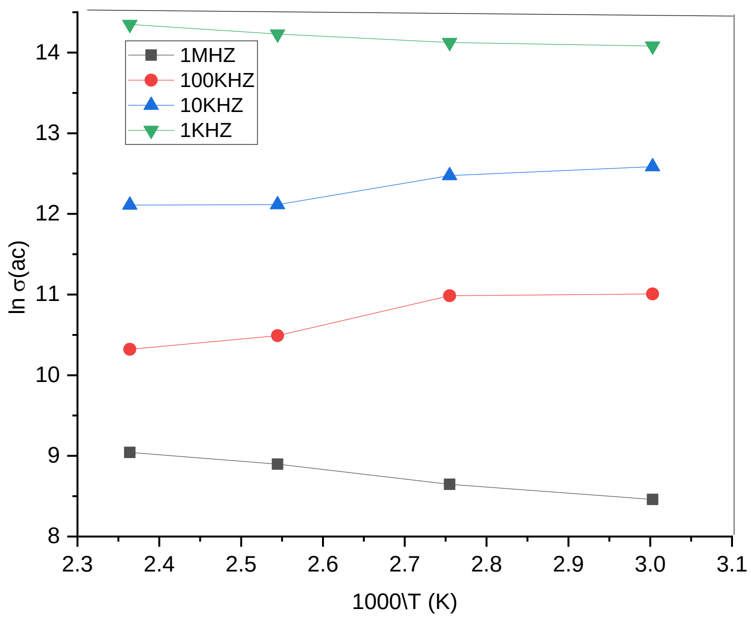


Fig .6d. Variation of ln$\sigma_{(ac)}$ with 1000\T for Na_2 SbF_5 single crystal.

3.6.1 Activation Energy

Arrehinus plot has been draw for the grown Na_2SbF_5crystal at 1 KHZ and100 KHZ were represented by Fig (6e) and Fig (6f). The activation energy has been estimated from the formula,

E_A= slope x k_B x 1000

Activation energy for the frequencies 1kHz,10kHz,100 kHz and 1MHz has been found as 0.0026529eV, 0.0024657eV, 0.0016062eV,and 0.00113 eV.The activation energy for the grown Na_2SbF_5crystal for the low activation energy reveals that the synthesized crystals have fewer defects and the defect free crystals become essential materials for fabrication of devices in optoelectronic industry [25].

Theoretical calculations shows that the high frequency dielectric constant is explicitly dependent on the valence electron plasma energy, and average energy gap referred as the penn gap and the Fermi energy. The penngap is determined by fitting the dielectric constant with the plasma energy valence electron plasma energy.

The molecular weight of the grown crystal is M=263 g/mol, the total number of valance electron Z=42 Density of the grown crystal was found to be ρ =3.59g-cm^3 and maximum dielectric constant is $\mathcal{E}_r$=35 .The valance electron plasma energy ($\hbar\omega_p$), is calculated using the relation,

$$\hbar\omega_p = \left(\frac{Z\rho}{M}\right)^{1/2}$$

Fermi energy in terms of plasma energy is given as,

$$\text{Ep} = \frac{\hbar\omega_p}{(\mathcal{E}_r - 1)^{1\backslash 2}}$$

$$E_F = 0.2948(\hbar\omega_p)^{4\backslash 3}$$

Polarizability ,α is obtained using the relation

$$\alpha = \left[\frac{(\hbar\omega_p)2s_0}{(\hbar\omega_p) + 3(E_p)^2}\right] \times \frac{M}{\rho} \ 0.396 \times 10^{-24} cm^3$$

S_0 is a constant for a particular material, and is given by

$$S_0 = 1 - \left(\frac{E_p}{4\,E_F}\right) + \frac{1}{3}\left(\frac{E_p}{4E_F}\right)^2$$

The value of α so obtained agrees well with that Clausius –Mossotti equation

$$\alpha = \left(\frac{3M}{4\pi N_a \rho}\right)\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\right) cm^3$$

where the symbols have their usual significance. N_a= 6.023x10^{23}is Avagadro number and the calculated parameters of sodium pentafluoro antimonite are listed in table 4.

Table. 4

Dielectric parameters of grown Na_2SbF_5 single crystals

Parameters	Values
Plasma energy(eV)	6.75
Pen energy(eV)	1.15
Fermi energy(eV)	3.74
Polarizability(cm^{-1}) (using Penn analysis)	2.88x10^{-23}
Polarizability(cm^{-1}) (using Clausius analysis)	2.669x10^{-23}

3.7 .Impedance Analysis

The bulk resistance and the electrical response of the grown crystalline material were determined using strongcomplex impedance measurement technique. The impedance spectroscopy was undertaken in order to collect the electrical features of the grown NSF crystal.

Generally, the data in the complex plane could be represented in any one of the basic forms such as complex impedance (Z), complex Admittance (Y'), complex permittivity (ε^*_r) and complex modulus (M).The complex impedance Presentation is used when the relaxation times of various processes differ as a consequences of different capacitive components. The complex impedance plot, called theNyquist plot, of the grown crystal sample gives one semi-circle arcs depending upon the relaxation times. Each of these semicircles could be represented by a single RC combination. The semicircle passes through a maximum frequency f, called therelaxation frequency and satisfies the conditionωτ=1. On the other hand, complex modulus or permittivity plots are used to represent the response of dielectric systems[23, 24]. Complex impedance plots of Z' versus Z'' are useful for analyzed by effective separation efficiency of photo induced electron hole pairs and a faster interfacial charge transfer, the dominant resistance of a sample but are insensitive to the smaller values of resistance, while the complex modulus plots are useful determining the smallest capacitance. Sinclair and west suggested the combined usage of impedance and modulus spectroscopic plots to rationalize the dielectric properties. Fig (9a) shows that Nyquistdiagram (Z' and Z'') at room temperature for pure Na_2SbF_5 grown at the sample.

Complex impedance measurement of the grown crystal was performed using a Versa STAT MC model LCR meter in the frequency range of 1Hz to 1MHz with the grown crystal held between two silver electrodes . At room temperature, it was accomplished by changing the frequency. Figure illustrates the Nyquist diagram of the NSF crystal. The DC conductivity of the sample was determined using the relation

$$\sigma_{dc} = {}^{t}/_{AR_b}\ \Omega^{-1}\text{m}^{-1}$$

Where 't' denotes the crystal thickness, A denotes the electrolyte's area, and Rb denotes the NSF crystal's bulk resistance. The calculated valueof DC conductivity for the NSF crystal is values are $\sigma_{dc} =$ 2.12834 x10^{-6} Ω^{-1}m^{-1}.DC conductivity values are low because charge carrier mobility decreases as ionic size decreases. The well –resolved semicircle at high frequency implies ionic conduction and the parallel combination of bulk capacitance and resistance. τ is the relaxation time.

$$\tau = \frac{1}{2\pi f_{max}}$$

Relaxationtime for grown Na_2SbF_5 crystal is 2.013373 sec. The total resistivity calculated using the formula,

$$R_t = R_b + R_{gh}$$

Total resistivity for grown Na_2SbF_5 crystal is 8774x10^{-6} Ω.The best fit equivalent model circuit was obtained by using the software Z-view. The value of grain resistance (Rg) and corresponding grain capacitance (Cgh) and corresponding relaxation frequency were obtained by using the software Z-viewunder simulation of data to obtain the best fit equivalent circuit.

A closer look at the Nyquist plot for the pure NSF crystals of Fig. 8b and 8c clearly indicates the steep rising arc and a presence of a one semi-circle near the origin. We can also analyzed by effective separation efficiency of photo induced electron hole pairs and a faster interfacial charge transfer. The inset Fig. 8a.indicates the presence of semi circle arc after fitting data with Z'(ohm) and Z''(ohm) forNa_2SbF_5single crystal.

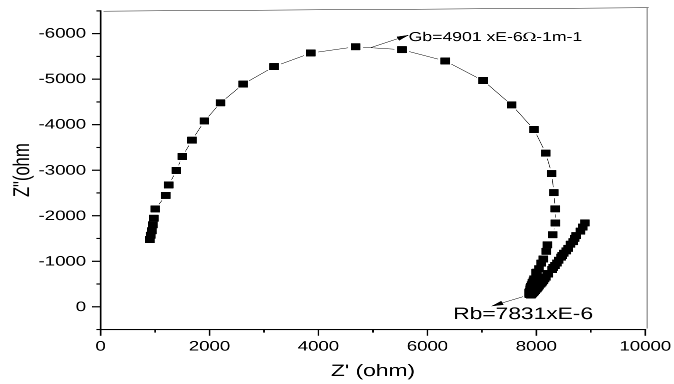


Fig 8a. Nyquist diagram (Z' and Z") for Na_2SbF_5single crystal

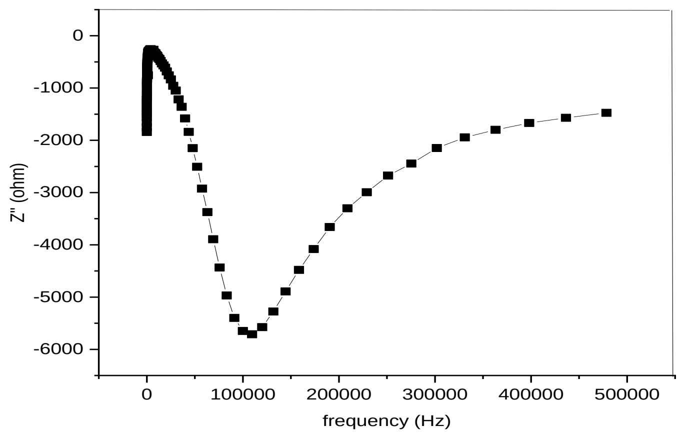


Fig. 8b. Variation of frequency (f) as a function of Z"(ohm) for Na_2SbF_5single crystal

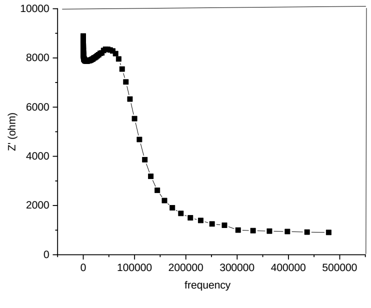


Fig.8c. Variation of frequency (f) as a function of Z'(ohm) for Na_2SbF_5single crystal

3.8. Photoluminescence spectral analysis

When a sample is exposed to ultraviolet (UV) radiation at a specific wavelength absorbs the energy of the light, gets excited, and produces UV or visible light that is longer than the incident light's wavelength. This phenomenon is known as photoluminescence. The emission spectrum of the sample is recorded using a spectrofluorometer.

The effective tools to provide relatively direct information about the physical properties of materials at the molecular level is Photoluminescence (PL) spectroscopy. The main parts of this instrument are monochromators a photomultiplier tube (PMT) that acts as the detector, and other electrical components.The Photoluminescence (PL) spectrum of Na_2SbF_5crystal recorded in the range between 300-500nm. The observed emission spectra ofNa_2SbF_5crystal'sare displayed in Fig.9. The two prominent emission peaks at 341 nm and 361 nm were observed.

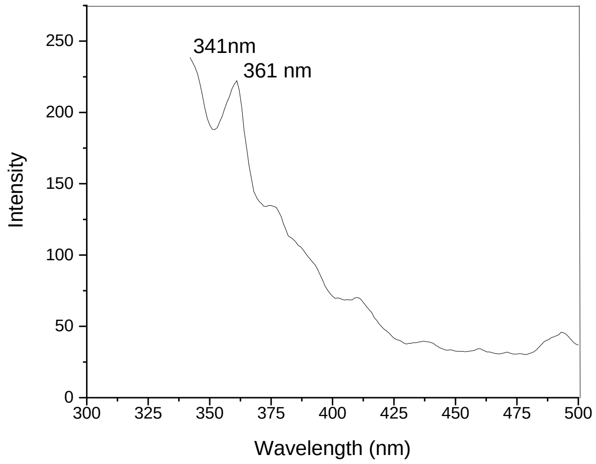


Fig. 9.PL emission spectrum of Na_2SbF_5Single crystal

3.10.NLO Studies

The three types of nonlinear optical (NLO) crystals are organic, inorganic, and semi-organic. Due to its extensive use in the domains of laser technology, optical communication, optical computing, photonics, and data storage technology, the nonlinear optical (NLO) crystals are gaining interest[26]. There are second order and third orderNLO studies in the field of NLO research [21,22].The crystal under study is an organic NLO crystal, second- andthird-order NLO analyses are performed on it.

3.10. Third - order NLO studies

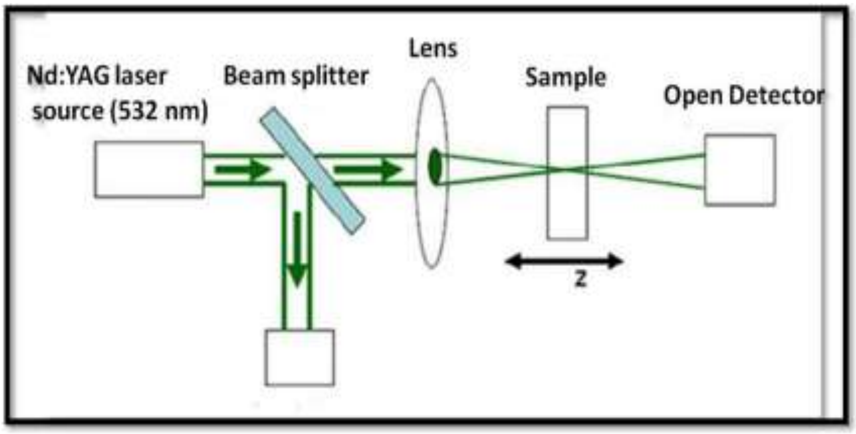


Fig. 3.10b .Schematic diagram of the Z-scan setup.

The z-scan method is a useful tool for measuring third-order nonlinear optical properties of the grown Na_2SbF_5 crystal. The nonlinear optical absorption (NLOA) coefficients identifyingunique features of nonlinear interactions.The open-aperture z-scan approach was used to measure the third order properties of the Na_2SbF_5Crystal.

A Q-switching Nd:YAG laser with a wavelength of 32 nm, energy of 100 µJ, and pulse width of 9 ns was used to perform the NLO measurement. The grown crystal sample with a linear transmittance of 65% was utilized for the measurement. The sample was maintained between the lens and the focal point in z-position. By moving the sample along the Z-direction toward or away from the focal point. The transmitted intensity was measured at various locations. The sample experiences various intensities at various points. The graphin between position and normalized transmittance was observed. The NLO coefficients are calculated by fitting the obtained z-scan data to standard NLO transmission equations [24]. The Z-Scan setup's schematic diagram is shown in Fig. 3.10b.

The open-aperture technique refers to nonlinear absorption of the material without an aperture. In open aperture Z-scan technique no aperture is present in front of the detector. Table 8.lists the different input settings for the open-aperture z-scan approach. The nonlinear absorption processare,saturable absorption (SA) or reverse saturable absorption (RSA). The grownNa_2SbF_5crystal's transmittance increases or decreases with input fluence, reaching a maximum or minimum at focus (maximum peak intensity at z=0). The OA Z-scan pattern of the grown Na_2SbF_5 crystals was shown in Fig.3.11(a). It shows a narrow valley pattern, as Stronger absorption appears at focus at the concentration at which reverse saturable absorption takes place, also known as the minimum transmittance at z=0. The concentration at which reverse saturable occurs.

The Sheik-Bahae method was used to fit the experimental data for normalized transmittance.

$$T = \left(\frac{1}{\sqrt{\pi} q_0(z,o)}\right) \int_{-\infty}^{\infty} ln\,[1 + q_0(z,o)e - \tau^2]\, d\tau$$

Where T is the normalized transmittance of the sample,

$$q_0(z,o) = \frac{\beta I_0 \boldsymbol{L_{eff}}}{\left(1 + \frac{z^2}{z_0^2}\right)}$$

whereβ is the effective nonlinear absorption coefficient, I_o is the intensity of the laser beam at thefocal point, and the sample length

$$L_{eff} = \frac{[1 - e^{(-\alpha l)}]}{\alpha}$$

The Rayleigh range $z_0 = \frac{\pi\omega_0^2}{\lambda}$

The beam waist radius of the focus is denoted byω_0^2. By fitting the experimental data, from the two-photon absorption mechanism. Two-photon absorption happens when the laser energy is greater than half of the band gap of the material (hv>Eg/ 2). The grown crystal can transmit low-intensity light while blocking high-intensity light. When an electron absorbs two photons to its band edge, it forms an optical limiter in the form of a crystal. The onset optical limiting threshold valueis3.01 x 10^{13} W/m^2. Table 9 shows estimated NLO coefficients. The generated NSF's two-photon absorption-induced optical limiting action makes it suitable for use in laser safety apparatus development for laser photonics applications. The optical limiting experiment can be used to determine the critical strength of the laser beam at which nonlinearity begins[23]. The produced crystal's optical limiting curve between input fluence (W/m^2) and normalized transmittance is shown in Fig.3.11(a).

Input parameters of the open aperture Z-scan technique for Na_2SbF_5 single crystals.

Laser Parameters	Numerical Values
Wavelength	532nm
Frequency	10HHz
Pulse Rate	9ns
Beam waist	16.9μm
Path length	1mm
Rayleigh Range	1.69mm
Focal length	15cm
Pulse energy	100μJ
Input intensity	2.46 x 10^{12} W/m^2

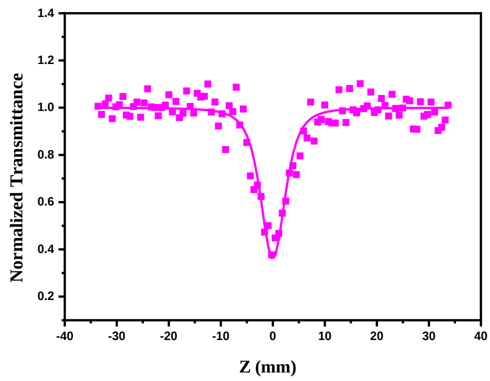
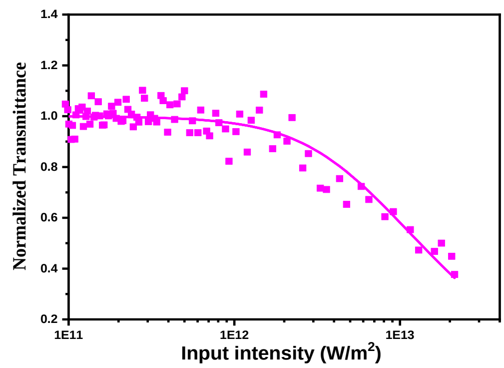


Fig 3.10a. Open-aperture Z-scan pattern of Na_2SbF_5 single crystal



F ig 3.11b : Optical Limiting pattern of Na_2SbF_5 single crystal

NLO coefficient	Values
Saturation intensity	$40x10^{11}$ W/m^2
Nonlinear absorption coefficient(β)	$1.5x10^{10}$ W/m^2
Onset Optical limiting threshold	$1.31x10^{12}$ W/m^2

Conclusion

Pure (Na)2SbF5 single crystals were grown by slow evaporation method using de-ionizedwater as Solvent at room temperature . The crystallinity nature of the given crystal has been conformedwith the help of XRD analysis. It crystallized in Orthorhombic system with lattice parameters a=5.495(6)A0,b= 8.087(1)A0 ,c =.11.194 A0,α = β =γ = 900 and has the space group of P212121. High degree of transparency is absorbed in the visible region as well as UV region and has a lower cut-off wavelengthof 240 nm transmission spectra are determined by UV-Vis studies. FTIR Spectra revealedthe various functional groups present in the grown crystal. EDX Studies represent the presence ofSodium penta fluoro antimonate in the grown crystals. The melting point of Na2 sbF5 crystals are thermally stable upto2930 C. Dielectric constant and dielectric loss factor of the samples have been measured at different frequencies and temperatures and these values are observed to be decreasing with increase of frequency and increasing with increase of temperature. Nyquist plot has been drawn for the grown crystals and calculated value of DC conductivity is σ_{dc} = 2.12834 x10-6 Ω-1m-1and discussed in PL studies two large peaks have been observed at361 nm in PL studies. The open-aperture Z-scan studies reveal that the grown Sodium penta fluoro antimonate exhibits reverse saturable absorption owing to two-photon absorption. The optical limiting threshold results shows that the grown crystal have potential applications in laser protection device . This Sodium penta fluoro antimonate crystals have unique optical properties so they can be suitable for designing various industrial photonic devices.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationshipsthat could have appeared to influence the work reported in this work paper.

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