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# Effect of 100keV $N^+$ Ion Irradiation on Semi-Organic Single Crystal of L-Arginine Phosphate Monohydrate Single Crystal for Nonlinear Optical Applications

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**Abstract:** ***The potential Semi-organic nonlinear optical material of L-Arginine phosphate monohydrate (LAP) single crystal has been grown by slow evaporation solution growth technique using water as the solvent. The well prepared single crystals of pure LAP were irradiated at room temperature with 100 keV Nitrogen ($N^+$) ions at fluence of $1x10^{16}$, $5x10^{16}$ and $1x10^{17}$ ions/cm$^2$. The pure and irradiated LAP single crystals were characterized by different characterization technique. The structural changes were analyzed by means of powder X-ray diffraction analysis. The functional groups of the pure and irradiated compound have been identified by FTIR. The photoluminescence and UV-Vis. absorption were done at room temperature and found that there is insignificant absorption in entire visible region. Vicker's microhardness technique was used to study effect on mechanical strength of crystal at different ion fluencies. The surface studies of the grown and irradiated single crystal were done by using the optical microscope and found that roughness of surface increases with increasing ion fluencies.***

**Keywords:** Single crystal**,** solution growth, non-linear optical material, irradiation

## 1. Introduction

Non-linear optical (NLO) single crystals has emerged as one of the most attractive fields of research in view of its potential applications in the area of optical switching, optical computing, optical data storage, optical bi-stability etc [1-4]. LAP is one of the promising non linear optical (NLO) material having chemical formula $(H_2N)_2^+CNH(CH_2)_3CH(NH_3)^+COO^-H_2PO_4 \cdot H_2O$. It crystallizes in monoclinic system with space group $P2_1$. Organic NLO materials are attracting much attention due to their high conversion efficiency for second harmonic generation, good transparency in the visible region and high resistance to optical damage and so on. However uses of organic materials are impended due their poor mechanical and thermal properties [5]. On the other hand, Inorganic NLO materials have good chemical stability, excellent mechanical strength, high optical quality and thermal properties. But Inorganic materials have low nonlinear properties relative to organic materials due to lack of  electron delocalization. In semi organic NLO materials, high optical nonlinearity of organic material is combined with the favourable mechanical and thermal properties of inorganic materials [6]. The single crystals of LAP have been grown by slow evaporation solution growth technique at room temperature. The good quality single crystals have been grown with the time span of 10 days. Many authors have been reported the L-Arginine Phosphate single crystals. The grown single crystals of LAP were subjected to $N^+$ ions beam with different ions fluencies. Interactions of energetic ions with crystalline materials induce the physical & chemical changes in crystal. When energetic $N^+$ ions impinge on the crystal, it causes displacement of lattice ions via collisions and cascade of displacements depending on ions, energy and properties of the medium [7]. These lattice displacements induce modifications in property of crystal including mechanical, optical absorption, luminescence and crystalline perfection [8, 9]. Effect of 100keV $N^+$ ion irradiation on organic single crystal of Hippuric acid for nonlinear optical applications [19].

In the present experimental study, the grown crystals were irradiated by 100 keV $N^+$ ions at fluences of $1x10^{16}$ ions / cm$^2$, $5\times10^{16}$ and $1\times10^{17}$ ions/cm$^2$ from the Low Energy Ion Beam Facility (LEIBF) at IUAC, New Delhi. The pure single crystals of LAP are shown in Fig.1. The title compound (LAP) belongs to semiorganic NLO material, and crystallizes in monoclinic system with unit cell parameters a=10.85 Å, b=7.91 Å, c =7.32 Å and space group $P2_1$ [10]. After the irradiation, its lattice dimensions, other optical, mechanical, dielectric and structural properties have been evaluated by different instrumentation technique. Many studies on L-Arginine phosphate monohydrate are already reported [11]. However this is the first report which carries information regarding the effect of ion irradiation on LAP single crystal. The observed results pure and irradiated LAP crystal will be presented in detail.

## 2. Experimental Details

### 2.1 Sample preparation

The single crystals of promising NLO material-LAP have been grown from the solution by slow evaporation technique using water as a solvent. The concentrated solution of LAP was prepared by dissolving the crystallized material with continuous stirring of the solution. Then the saturated solution was filtered by using Whatmann filter paper for further purification of the solution. The filtered solution was tightly


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packed and housed in a constant temperature bath (CTB) with a setting temperature of $30^0$C. Good quality single crystals have been harvested from the mother solution, within 10 days as shown in Fig.1.

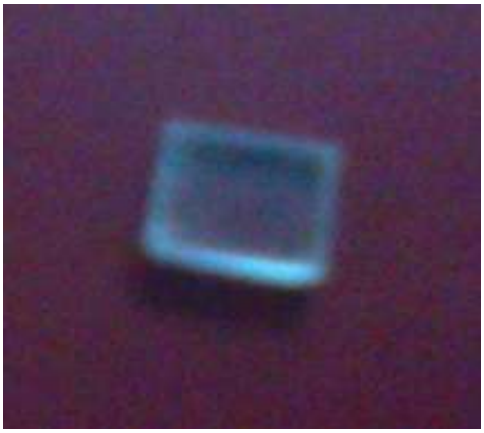


**Figure 1:** Photograph of LAP single crystal

### 2.2 Ion Irradiation Details

The as grown LAP crystals were well polished and then subjected to irradiation at different ion fluences. The projected ranges $N^+$ ions in the LAP crystals were calculated by SRIM-2006 which ascertains the penetration of ions into the crystal lattice. The nuclear energy loss ($S_N$) and the electronic energy loss ($S_E$) values in the LAP crystals are given in Table.1 for $N^+$ respectively, as obtained from the SRIM-2006 calculations.

**Table 1:** Energy loss, projected range and energy straggling for 100keV $N^+$ ions

| Ion energy | dE/dx (elec.) eV/ Å | dE / dx (nuc.) eV/ Å | Projected Range | Longitudinal straggling | Lateral straggling |
|---|---|---|---|---|---|
| 100.00keV | 1.448E+01 | 3.537E+00 | 5346 Å | 1192 Å | 1092 Å |

Since the $S_E$ value is larger than the $S_N$ value, the incident $N^+$ ions lose energy predominantly via inelastic collisions with the target electrons.

## 3. Results & Discussions

### 3.1 Powder X-ray Diffraction

The pure and irradiated single crystal of semi-organic LAP were analyzed by adopting Bruker D-8 Advance X-ray powder diffractometer using CuKα radiation of wavelength 1.54 Å at a scan speed of $1^0$ /sec. The recorded patterns are shown in Fig.2.

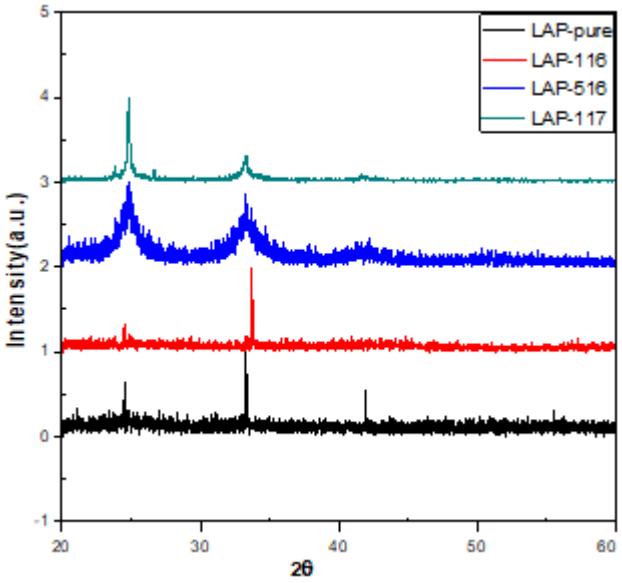



**Figure 2:** Powder X-ray diffraction pattern of pure and irradiated single crystal

The observed peaks were analyzed with POWDERX software and the observed lattice dimensions of pure and irradiated LAP acid are shown in Table.2, which is in good agreement with the reported single crystal XRD data. From the XRD pattern, we found that relative intensity of peak is decreasing and width of the peaks increases on irradiation which indicate that crystallinity of the irradiated samples is decreasing with irradiation, which may be due to production of point/clusters defects along the ion trajectory [12]. It is clear that the lattice strain in crystal increases due irradiation. Hence, it can be concluded that the strain developed due to the created defects is responsible for the modification of different properties of LAP crystals. From the analysis, we observed that there is no change in the phase structure of the irradiated samples, but there are changes in the lattice parameters (Table.2).

**Table 2:** The lattice parameters of pure and irradiated single crystal of LAP

| Sample Name | a | | c |
|---|---|---|---|
| LAP-pure | 10.8698 | 7.8451 | 7.2983 |
| LAP -1x$10^{16}$ | 10.8713 | 7.9211 | 7.3018 |
| LAP -5x$10^{16}$ | 10.8409 | 7.9461 | 7.3286 |
| LAP -1x$10^{17}$ | 10.8506 | 7.9201 | 7.3059 |

### 3.2 FTIR Analysis

The different functional groups of pure and irradiated LAP were identified by FTIR studies in the range 4000-400 $cm^{-1}$. The band vibration of $PO_4$ is tentatively assigned at wave number 526 $cm^{-1}$ in the IR spectrum and OH out of plane deformation is observed at 611.4 $cm^{-1}$. The N-H wagging (out of plane bending) of the compound are identified at peaks with wavenumber of 690.6 $cm^{-1}$. The rocking vibration of $NH_2$ is observed at 775.4 $cm^{-1}$. The P-OH stretching is observed at 873.75 and 948.9 $cm^{-1}$ in the IR spectrum. A band at 1149.6 $cm^{-1}$, 1195.9 $cm^{-1}$, may be due to C-N stretching. The C-H bending vibrations are identified at 1417 $cm^{-1}$. The band at


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1660.7 and 1670.4 $cm^{-1}$ are observed due to stretching vibrations of $COO^-$. The band at 2343.5 $cm^{-1}$ and 1924.9 $cm^{-1}$ due to hydrogen bonding interaction in compound. The band at 2943.7 $cm^{-1}$ is due to asymmetric stretching vibrations of δ $(CH_2)$.

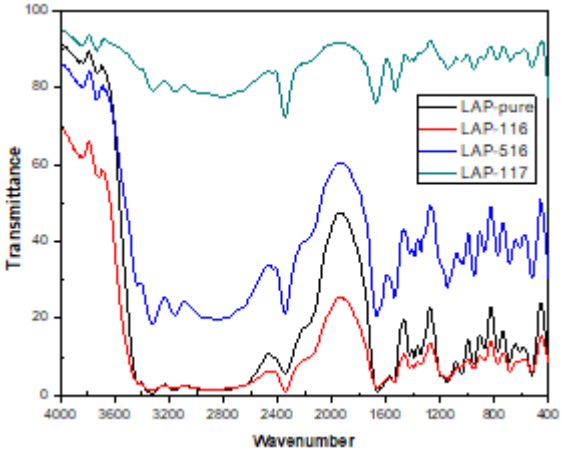



**Figure 3:** FTIR spectrum of pure and irradiated single crystal

The band at 3161.3 $cm^{-1}$ is observed at $NH_3^+$ asymmetric stretching. The sharp and intense band is observed at 3325.8 $cm^{-1}$ may be due to N-H stretching vibration and the band at 3425.6 $cm^{-1}$ is the evident of ν (OH) $H_2O$ vibrations. $NH_2$ stretching vibration is observed at 3732 and 3714 $cm^{-1}$. The FTIR spectrum of irradiated LAP shown in Fig.3 is closely similar to that of pure compound. Hence, we can say that there is no change in the chemical nature of L-Arginine Phosphate monohydrate due to irradiation and irradiation on the sample might give energy to dislocate molecules in the lattice which may in turn weakens the intermolecular bonding. Hence it can be concluded that there is no change in functional group for grown as well as irradiated crystals.

### 3.3 UV-Vis-NIR analysis

The UV-Vis-NIR analysis was carried out between 200 to 1100 nm using SHIMADZU (model-1601) UV-Visible-NIR spectrophotometer. The recorded UV-absorption spectrum is shown in Fig.4. From these measurements, we found that the cut-off wavelength are 321 nm, 264 nm, 250 and 247 nm for pure and irradiated L-Arginine Phosphate single crystal at fluence $1x10^{16}$, $5x10^{16}$, $1x10^{17}$ respectively. It is noted that there is no significant absorption in the entire visible region, which enables it to be a potential candidate for optoelectronic applications. The cut off wavelength was found to decrease with increase in fluence of ions which indicate that band gap of crystal is increasing with increasing dose. The change in band gap may be due to structural changes which have been created by $N^+$ ions. The absorption is decreased with increase of ion fluences which may be due to formation of defect centre which forms scattering of light within the sample [13].

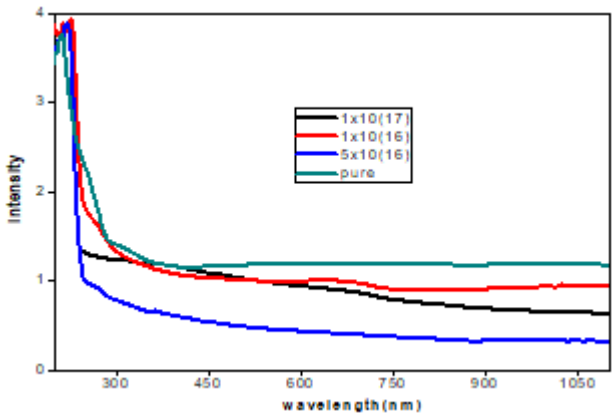



**Figure 4:** Plot of Absorbance vs. wavelength (nm) for pure and irradiated LAP single crystal

### 3.4 Photoluminescence Analysis

Photoluminescence (PL) spectroscopy is the standard technique for characterizing defects, vacancies and other imperfections existing in the single crystal. Emission spectrum of pure and irradiated LAP single crystals was recorded at the excitation wavelength of 261 nm using a Perkin-Elmer luminescence spectrometer (model: LS-55) at room temperature as shown in Fig.5.

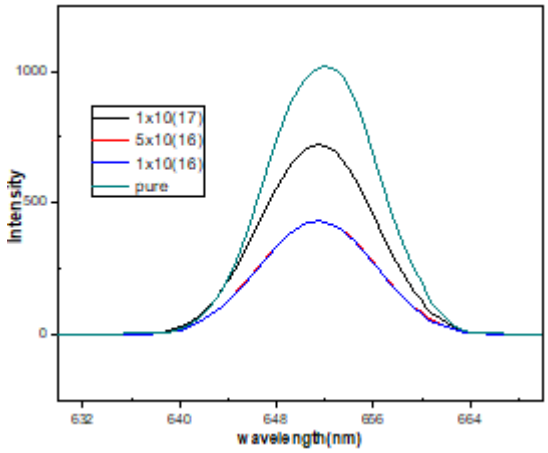



**Figure 5:** Photoluminescence spectrum of pure and irradiated single crystal of LAP.

The pure and irradiated LAP single crystals exhibit a high intensity PL emission at 652 nm respectively. The absorption leads to a strong emission in the red region. From the graph, we observed that the PL intensity is affected by defects created by $N^+$ ions. Initially, a strong PL intensity indicates dominant radiative transitions. The observed PL spectra of pure and irradiated samples do not show any shift in the band position. This observation suggests the existence of states, which remain unaffected by irradiation. The peak intensity has decreased when compared to that of the pure sample. The PL intensity is sensitive to the damage created by low energy $N^+$ ions. With increase of fluence, the sample becomes rich with defects, which affect the radiative transitions. Thus, due to the excessive defects, the radiative transition rate decreases, resulting a decrease of the integrated PL intensity from the


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LAP sample with increase of fluence [14]. The decrease in PL intensity may be recognised to lattice deformation produced by displacement of cations in the irradiated region.

### 3.5 Hardness Measurement

The Vickers micro hardness studies were carried out using a Vickers hardness (Make: Metatech, Pune) tester equipped with a diamond square indenter. The Vickers micro indentation hardness of pure and irradiated semi-organic LAP single crystals were investigated on crystallographic plane at indentation test loads ranging from 5 to 75 gram and time of indentation was kept 10 sec. The average value of the diagonal lengths of indentation mark was used to calculate the hardness of the sample. The hardness of the crystals is calculated using the relation [15]

$$H_v = \frac{1.854 * P}{d^2} (kg/mm^2)$$

Where $H_v$ is the Vickers hardness number, $P$ is the indentation load in kg and $d$ is the diagonal length of the indentation in mm. The calculated hardness values for LAP single crystals are plotted in Fig. 6 and it is observed that initially the hardness value increases nonlinearly with load.

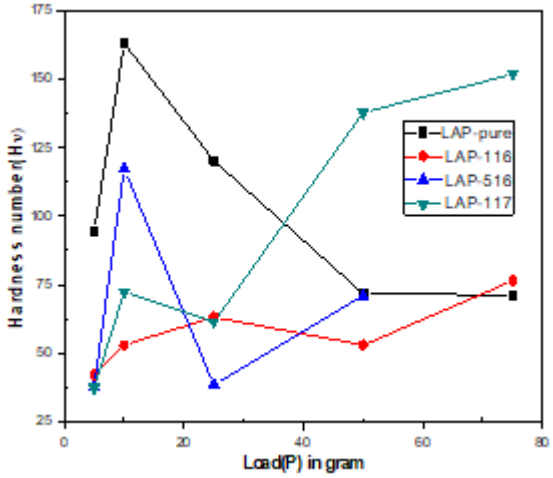



**Figure 6:** Variation in the Vickers hardness $H_v$ with load P (grams).

The nonlinear variation may be due to imperfections like interstitials defects, impurities, vacancies, dislocations, low angle grain boundaries etc. It is also observed that hardness decreased with increase of $N^+$ ions fluence, which may be recognized due to high porosity. According to the Hays – Kendall approach, load dependent hardness is given by [16]

$$P = W + A.d^2$$

Where $W$ is the minimum load to initiate plastic deformation and $A$ is a load independent constant. The estimated values of $W$ and $A$ which were calculated from the plots drawn between $P$ and $d^2$ (Fig. 6a),

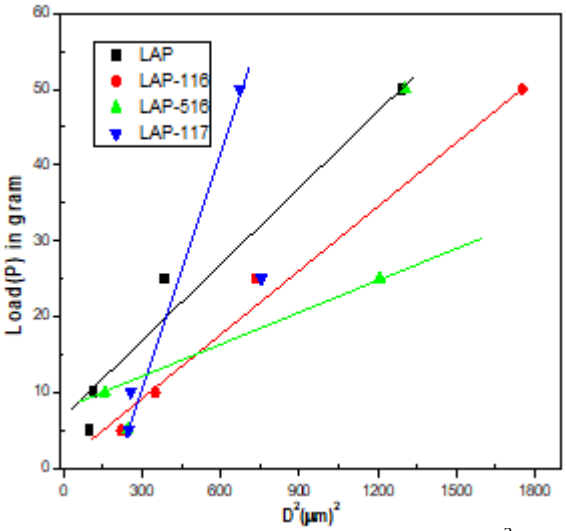



**Figure 6a:** Variation in the load P (grams) with $d^2$ ($mm^2$)

where $W$ is the intercept along the load axis and A is the slope. The corrected hardness $H_0$ for these crystals has been estimated using the relation, $H_0$ = 1854 A. The $W$ and $Ho$ values for pure, irradiated single crystals are given in Table.3 respectively. The relationship between load $P$ and size of the indentation is given by Meyer's law [17] as, $P = kd^n$, Where P is the load applied, d is the diagonal length of impression, k is a constant of material and n is Meyer's index. The value of 'n' (shown in Table.3) is estimated from the slope of ln P vs. ln d plot which is shown in the Fig. 6b.

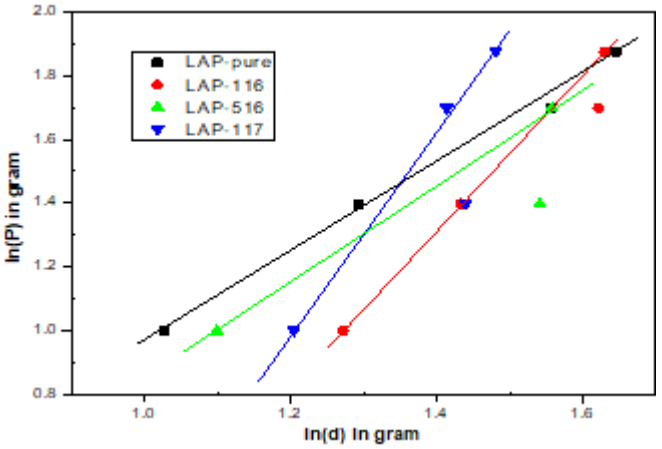



**Figure 6b:** Variation in the ln (P) with ln(d)

Onitsch and Hanneman [18] had shown that the value of n comes out to be 1–1.6 for hard materials and more than 1.6 for soft ones. From this analysis, we found that the present crystal belongs to the category of soft material.

**Table 3:** The value of n, $H_0$, W for pure and irradiated LAP single crystal

| Parameter | pure | Irradiated ($1x10^{16}$) | Irradiated ($5x10^{16}$) | Irradiated ($1x10^{17}$) |
|---|---|---|---|---|
| Meyer Index, n | 1.6 | 2.3 | 1.6 | 3.3 |
| $H_0$ | 65.6 | 68.4 | 53.9 | 157.3 |
| W | 5.82 | -2.98 | 1.28 | -15.23 |


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### 3.6 Surface Studies

The Micrograph patterns of the pure and irradiated LAP singles have been recorded with help of optical microscope in transmission mode. In this mode, Polariser and analyser have crossed positions at $45^0$ angle. The recorded patterns of the pure and irradiated single crystal are given in Fig. 7.

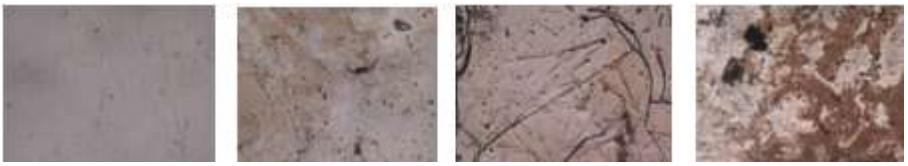


**Figure 7:** Micrograph of pure LAP and irradiated single crystals (a: pure, b: 1x10(16) c: 5x10(16,d: 1x10(17)

From the figure, we analysed that grown single crystal has uniform surface having pits. The surface of the irradiated samples is having non-uniform defects and the surface defects are increased with the increase of ions. As the ions fluence is increased, surface became more and more amorphous. Its crystalline nature is decreased with increased of the ions fluence.

## 4. Conclusions

The grown good quality single crystal of LAP was subjected to irradiation at different ions fluences. The lattice parameter values were determined from Powder X-ray diffraction and found that the compound crystallizes in monoclinic crystal system. The presence of various functional groups was identified from FTIR spectroscopic analyses. The UV-Vis and PL studies shows that there is no absorption in the entire visible region and band gap of material increase with increase of ion dose. From the Vickers hardness analysis we found that the Meyer index (n) of the crystal is increasing with irradiation, sample is becoming more soft after irradiation. Micrograph studies of the pure and irradiated single crystal shows that roughness of the surface is increased with increased of the ion fluencies. Surface is becoming more and more amorphous with increase of the ion dose.

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