In this work, c-axis oriented lithium niobate thin film has been deposited on Sapphire single crystal substrate by pulse laser deposition. X-ray diffraction showed only reflections corresponding to (006) and (0012) planes of LiNbO$_3$ on (001) sapphire substrate, indicating that growth of texture LiNbO$_3$ film on sapphire. The estimated value of c-axis lattice parameter is found to be 1.36 nm and is close to the value reported for LiNbO$_3$ single crystal. Optical properties of films has been studied using UV-Vis spectrophotometer and the estimated value of refractive index at 640 nm is $n = 1.76$ nm. A slight dispersion in the refractive index has been observed with photon energy below the interband absorption edge. Raman scattering studies made on prepared sample in the back scattering geometry with incident light normal to the film surface in Z(X+Y,X+Y) Z configuration indicate the formation of single phase material and free from any type of lattice defects.

Ferroelectric material has been an interesting material because of its good piezoelectric, electro-optic and non-linear optical coefficient for various applications. Lithium niobate is one of the most suitable material for electro-optic, optical waveguide and SAW devices because of its good electro-optic, piezoelectric, pyroelectric, photo-elastic and non-linear properties. Lithium niobate single crystals has been used extensively for these applications but the deposition of thin film offers great advantages because of applicability of high electric field at low voltage and in the applications where high refractive index material is needed. Sapphire single crystal has the same crystalline structure as lithium niobate with low refractive index which makes it suitable to grow good quality LiNbO$_3$ film for wave guiding and non-linear optical studies. Different deposition techniques such as sputtering, chemical vapour deposition, sol-gel and pulse laser deposition (PLD) have been utilized to fabricate LiNbO$_3$ thin films. Among these, PLD is the promising one for its ability to reproduce the composition of the target in the film and secondly it yield good quality film at relatively low temperature. Sapphire is a good substrate to grow oriented lithium niobate thin film because of same crystalline structure as lithium niobate with nearly same lattice parameters. In this paper, the structural and optical properties of lithium niobate thin film grown on sapphire substrate by pulse laser deposition have been reported.

**Experimental Procedure**

Pulse laser deposition has been used to fabricate lithium niobate thin film on sapphire substrate using KrF excimer laser operating at 248-nm with laser pulse width of 10 ns, energy density of $3 \text{ J cm}^{-2}$ and repetition rate of 10 Hz. A high density ceramic target was prepared by making a 20 mm diameter pellet of lithium niobate powder mixed with 5% excess of lithium oxide and then sintered it for 2 h at 1075°C. Film was grown at 700°C substrate temperature under 100 mTorr oxygen pressure. The structural properties and lattice parameters were determined using X-ray diffraction (XRD) method. UV-Vis spectroscopy has been used to estimate the band gap and refractive index of film. The quality of the film and phase purity has been identified using Raman spectroscopy. Coherent Ar+ laser polarized light of $\lambda = 514.5$ nm was used for Raman spectra and then analyzed it through spectrometer with a charge coupled device in a backscattering geometry.

**Results and Discussion**

The LiNbO$_3$ thin film deposited by PLD on (0001) sapphire single crystal substrate was found to be transparent, smooth, and strongly adherent. Figure 1 shows the XRD pattern of LiNbO$_3$ thin film deposited on sapphire substrate. Two peaks corresponding to
(006) and (0012) planes of lithium niobate and one peak corresponding to (006) plane of sapphire were observed at 2θ = 39.2°, 34.3° and 40.7° respectively, showing the growth of textured LiNbO₃ film having crystallites oriented along preferred direction with c-axis normal to the sapphire surface. The shift in the diffraction peak position from single crystal value is mainly associated with the presence of strain in the deposited film. The angular peak position of deposited film is slightly higher than the bulk value, indicating that films are in a uniform state of stress with tensile component parallel to c-axis. The presence of sharp and intense XRD peaks indicates the important role of underneath lattice matched sapphire substrate for nucleating the crystallites of LiNbO₃ along preferred growth direction. The c-axis lattice parameter of the deposited film was calculated from the observed XRD peak and found to be 1.36 nm which is close to the value 1.38 nm reported for LiNbO₃ single crystal. The slight low value of lattice constant for deposited film in comparison to single crystal indicate that the unit cell is compressed along c-axis, and tensile forces act in the plane of the film.

**Optical properties**

Figure 2 shows the transmission spectra of deposited thin film with reference to air as a function of wavelength. The transmission spectrum exhibits high transmission in the visible range and shows a sharp fundamental absorption edge at about 250 nm. The presence of well defined interference fringes in the optical spectra indicates the growth of good optical quality film free from any type of inhomogeneity.

Figure 3 shows the plot of square of absorption coefficient α² with photon energy, hν. The absorption coefficient can be calculated by considering the value of transmittance and film thickness. The value of band gap of 0.8 µm thick LiNbO₃ thin film estimated from the extrapolation of linear curve of Fig. 3 to α² = 0 was found to be about 4.5 eV.

The refractive index, n(λ), of the film was obtained from the observed interference fringe pattern in the transmission spectrum using

\[
n = [N + (N^2 - n_0^2 n_s^2)^{1/2}]^{1/2}
\]

where \(N = (n_0^2 + n_s^2)/2 + 2n_0 n_s (T_{\text{max}} - T_{\text{min}})/T_{\text{max}} T_{\text{min}}\)

\(N\) can be calculated from the values of \(T_{\text{max}}\) and \(T_{\text{min}}\) at same wavelength from the enveloped made on the fringes pattern, \(n_0\) and \(n_s\) are the refractive indices of air and substrate respectively. The estimated value of refractive index of the LiNbO₃ film was found to be
1.7 at 640 nm. It has also been seen that refractive index decreases with increasing value of wavelength.

**Raman spectroscopy**

Figure 4 shows the Raman spectrum of oriented lithium niobate thin film deposited on sapphire substrate recorded in the backward scattering geometry under Z(X+Y,X+Y)Z configuration where Z is the direction of incident light along c-axis normal to the film surface, and X and Y are the direction of polarization along a and b axis in the plane of film. According to selection rule 4A (LO) +9E (TO) fundamental frequencies are allowed in the LiNbO$_3$.

The observed phonon modes in the Raman spectra in agreement to the selection rule and similar to that observed in the z-cut LiNbO$_3$ single crystal. The observed spectra show the growth of textured LiNbO$_3$ thin film on sapphire substrate free from any type of lattice deformation.

**Conclusions**

Highly textured and c-axis oriented LiNbO$_3$ thin film has been grown on (0001) sapphire substrate using PLD. The structural and optical parameters of deposited films are close to the single crystal value. Raman spectroscopy analysis confirms the growth of defect free film with good optical quality.

**References**