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Micro-Raman spectroscopy of photonic device materials: Group theory and polarization selection rules

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Micro-Raman spectroscopy has certain inherent advantages when used for materials characterization, particularly as applied to photonic and microelectronic devices. The diffraction limited beam diameter that can be achieved is well suited to the spatial resolution required for the *in situ* analysis of such devices. In addition, the nondestructive nature of Raman scattering makes it suitable for process analytical spectroscopy in the clean room. The sensitivity of Raman scattering to crystal structure and strain has led to the increasing use of micro-Raman spectroscopy for the characterization of solid-state microelectronic devices as described by Perkowitz [1]. Now, with the increasing use of photonic devices in optical communications, micro-Raman spectroscopy will play an even more important role in materials characterization, device design, and failure mode analysis. Micro-Raman spectroscopy is an optical method that probes the very chemical bonding and crystal structure affecting the optical properties and performance of photonic devices.

The optical properties of a material are highly dependent upon its long-range translational symmetry (*i.e.*; amorphous, single crystal, polycrystalline). Specifically, the crystal class to which the material belongs will dictate the refractive index, nonlinear, and electrooptic coefficients of crystalline materials. The Raman polarization selection rules of solid-state materials are also dictated by crystal symmetry, and they can be applied to correlate chemical bonding and crystal structure to directional dependent optical properties of photonic devices. Because the Raman spectrum consists primarily of bands arising from the fundamental vibrational modes of the material, group theory can be more directly applied to the interpretation of the spectra. Herein lies a primary advantage of micro-Raman spectroscopy for the characterization and process control of photonic device microchemistry.

The polarization sensitivity of micro-Raman spectroscopy and its value in probing photonic device structure has been demonstrated in studies of $Li_{1-x}H_xNbO_3$ optical waveguides by Paz-Pujalt [2]. Single crystals of Z-cut $LiNbO_3$ are treated with acid under controlled conditions, thereby inducing a depth dependent refractive index through the partial ion exchange of H^+ for Li^+. The ion-exchanged regions of $Li_{1-x}H_xNbO_3$ have a higher extraordinary refractive index than does the surrounding $LiNbO_3$, and so optical confinement of a Z-polarized laser beam endfired into the X-face of the $Li_{1-x}H_xNbO_3$

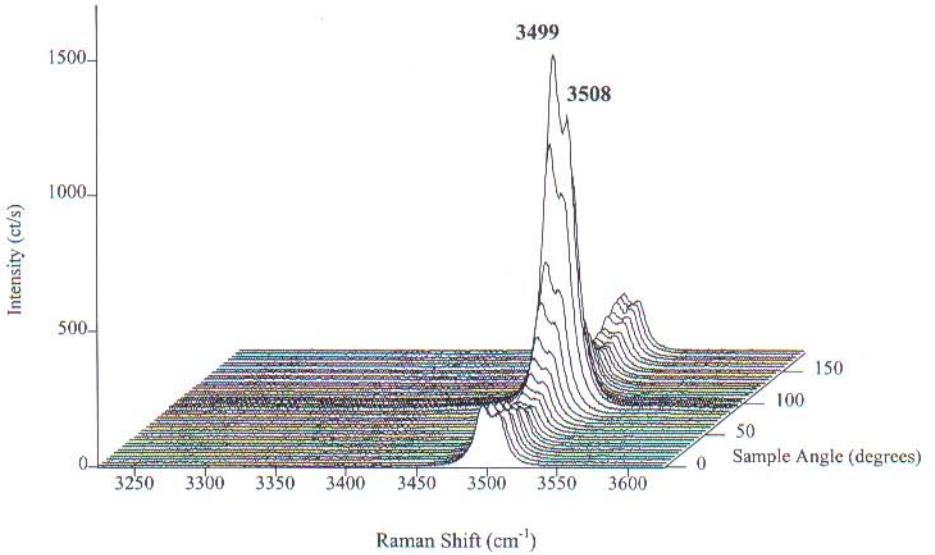

Fig. 1 Polarization/Orientation micro-Raman spectra obtained from the X-face of a planar waveguide fabricated by partial H^+-exchange of $LiNbO_3$. A sample angle of 90° corresponds to the extraordinary (Z-) axis. Analyzer parallel to incident polarization.

can be achieved. The basis for the directional dependence of the increased refractive index is revealed by the Polarization/Orientation (P/O) micro-Raman spectra shown in Fig. 1. The P/O spectra of the OH stretching mode, which is absent in $LiNbO_3$, correlate precisely with the extraordinary (Z-axis) refractive index changes in $Li_{1-x}H_xNbO_3$. P/O micro-Raman spectra provide information regarding PE-induced changes in chemical bonding and crystal structure, which are related to the nonlinear and electrooptic properties of the device. Furthermore, we have found that the polarization of the OH stretching mode is dependent upon the crystal axis along which the ion exchange was induced. We will discuss how the polarization sensitivity of micro-Raman spectroscopy, in conjunction with group theory, makes it a powerful tool for *in situ* characterization of solid-state photonic devices.

References

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2. Paz-Pujalt G, Tuschel D, Braunstein G, Blanton T, Lee S-T and Salter L 1994 J. Appl. Phys. **76**, 3981