Propagating Optical Modes in PST Ferroelectric Thin Films

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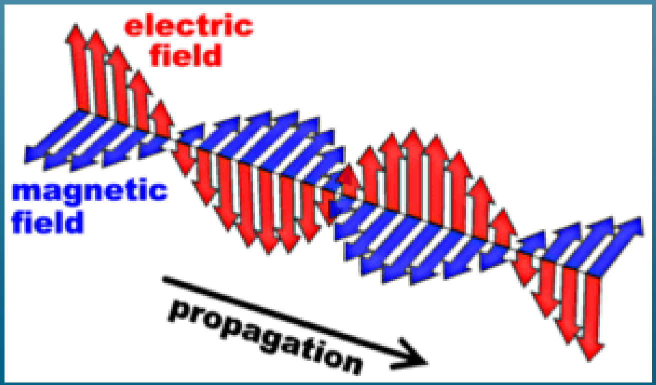
Agenda

- Overview of Nonlinear Optics and Thin Film Optics and Technology
- Motivation
- Experimental Methods
- Results and Conclusions
- Acknowledgments

Polarization and Electromagnetic Wave Propagation



- Light is an electromagnetic wave described by the three-dimensional wave equations:

$$\nabla^2 \tilde{E} = \frac{1}{c^2}\frac{\partial^2 \tilde{E}}{\partial t^2} \qquad \nabla^2 \tilde{H} = \frac{1}{c^2}\frac{\partial^2 \tilde{H}}{\partial t^2}$$

- Polarization density describes how susceptible a material is to light with a given TE field:

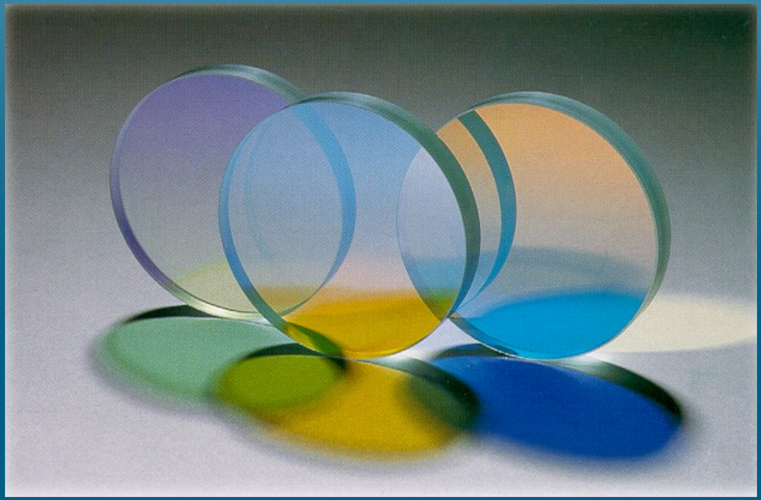
$$\tilde{P}(t) = \chi^{(1)}\tilde{E}(t)$$

Linear vs. Nonlinear Optics

- In linear optics, polarization dependent on electric field as $P = \chi^{(1)}E$
- In nonlinear optics, polarization dependent on electric field as $P = \chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + \ldots$
- Nonlinear optical effects occur at high intensities and include second-harmonic generation (frequency doubling) and intensity-dependent refractivity
- Nonlinear refractive index γ related to overall refractive index by $n = n_0 + \gamma I$ and is also related to third-order susceptibility $\chi^{(3)}$
- Third-order frequency-dependent absorption coefficient β related to third-order susceptibility $\chi^{(3)}$

Thin-Film Optics and Technology

- Thin films are solid-state materials with thicknesses generally less than 1 μm
- Wavelength and subwavelength thicknesses result in high reflectivity
- Can be layered to produce interference at interfaces for filtering, etc.
- Applications: optical bandpass filters, optical antireflective coatings



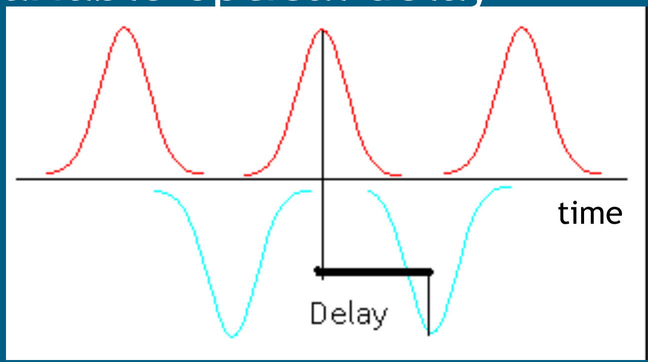
Dichroic (thin-film bandpass) optical filters comprised of layers of thin-film optical materials

Motivation

- The current project aims to determine the candidacy of PST thin films for applications in nonlinear and integrated optics with a final goal of experimentally deducing the third-order nonlinear absorption coefficient (β) and the third-order nonlinear refractive index (γ) using a novel nonlinear prism coupling technique

Experimental Methods

- $Pb_{0.35}Sr_{0.65}TiO_3$ thin films were deposited on (001) MgO substrates using pulsed laser ablation at oxygen pressures from 50 mTorr to 450 mTorr at 100 mTorr increments
- Optical pathway designed to allow for the coupling of transverse electric (TE) and transverse magnetic (TM) mode beams into the thin films with a variable optical delay

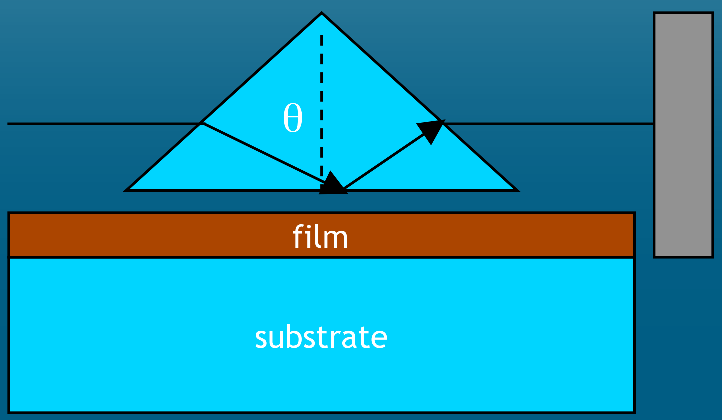


Experimental Methods

- Optical delay between the propagation of the TE and TM modes modulated by a pump-probe system and is on the order of femtoseconds
- Zero-delay point (i.e., point at which TE and TM pulse trains are in phase) determined by pump-probe reflectivity techniques
- Prism coupling method used to determine modal angles for the PST thin films under TE-polarized beams, TM-polarized beams, and TE-TM coupled beams for many points within a radius of the zero-delay point
- Analysis of modal angle data allows for calculation of film thickness, refractive index, and in the case of the TE-TM coupled beam, third-order nonlinear absorption coefficient (β) and refractive index (γ)

Prism Coupling

- Prism coupling technique allows for coupling of thin film to prism head
- Incident beam strikes the prism at a certain incident angle θ which is varied
- Thin film reflects incident beam for most values of θ
- Photodetector measures reflected intensity

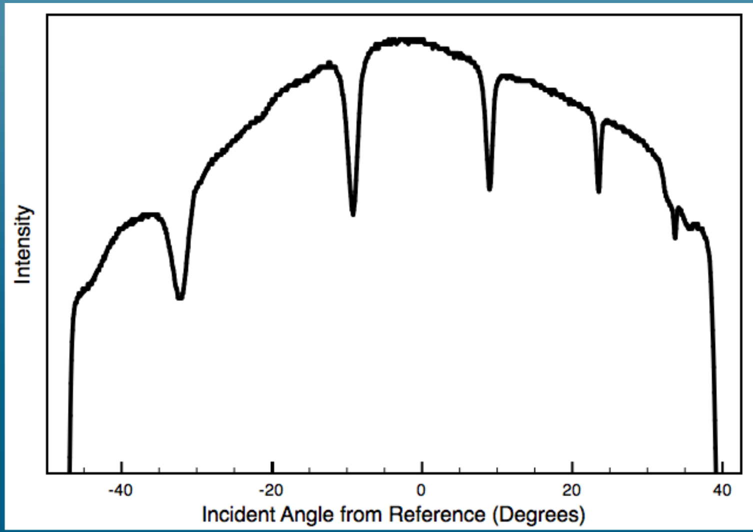


Optical Tunneling

- For certain values of the incident angle θ (mode angles), much of the incident beam's power is tunneled into the thin film rather than being reflected
- At mode angles, reflected intensity drops distinctly and sharply
- Mode equation:

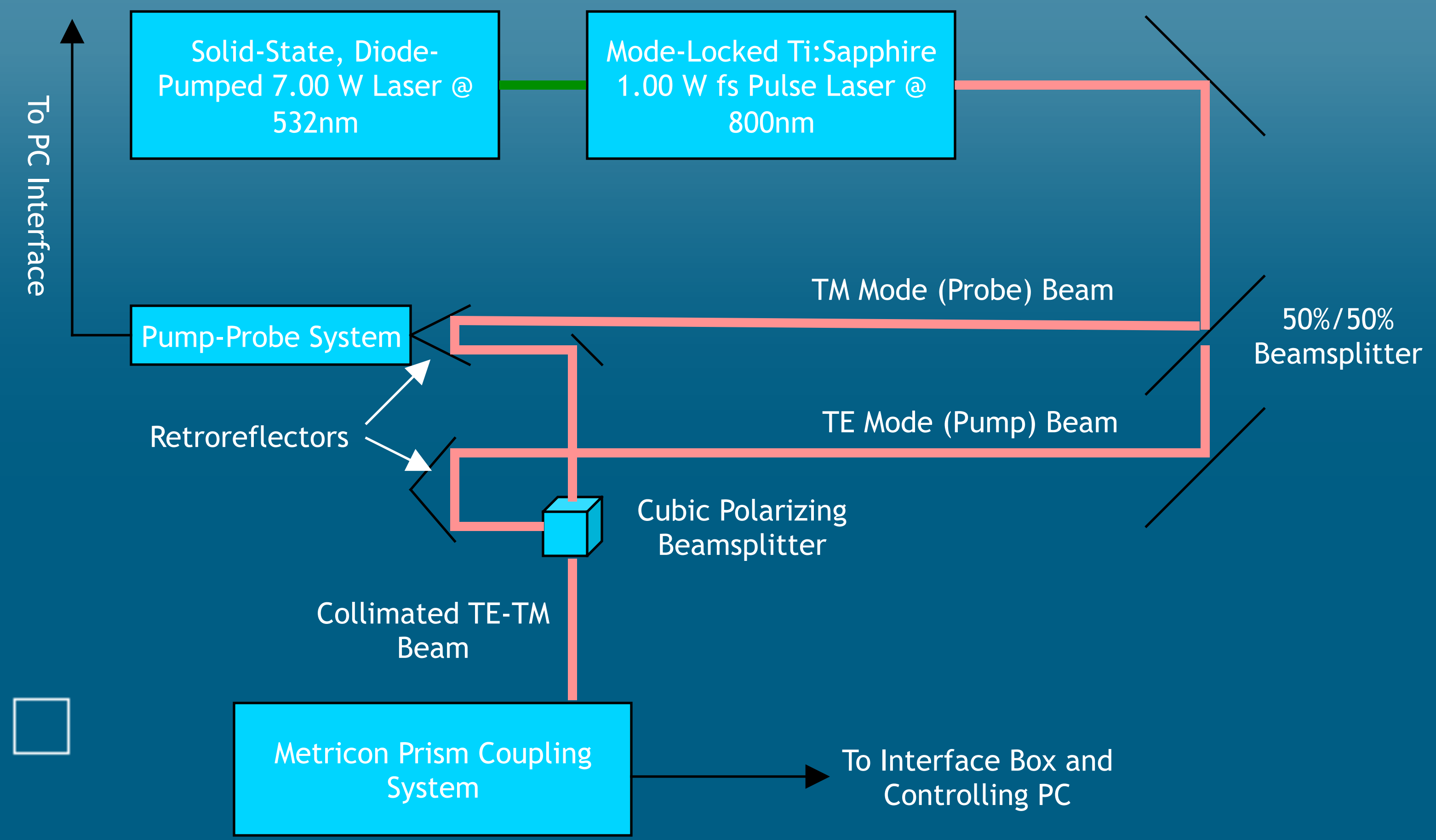
$$\frac{2\pi}{\lambda} nT\cos(\theta) + \psi_{10} + \psi_{12} = m\pi$$

allows for calculation of film thickness *T* and refractive index *n* based on mode angles



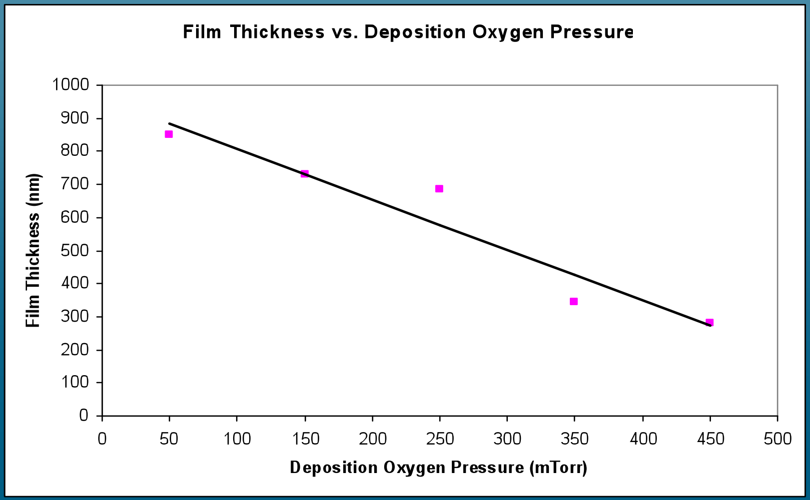
Intensity vs. incident angle plot for 50 mTorr PST sample with 633 nm incident beam showing five mode angles

Optical Setup for Thin Film Measurements



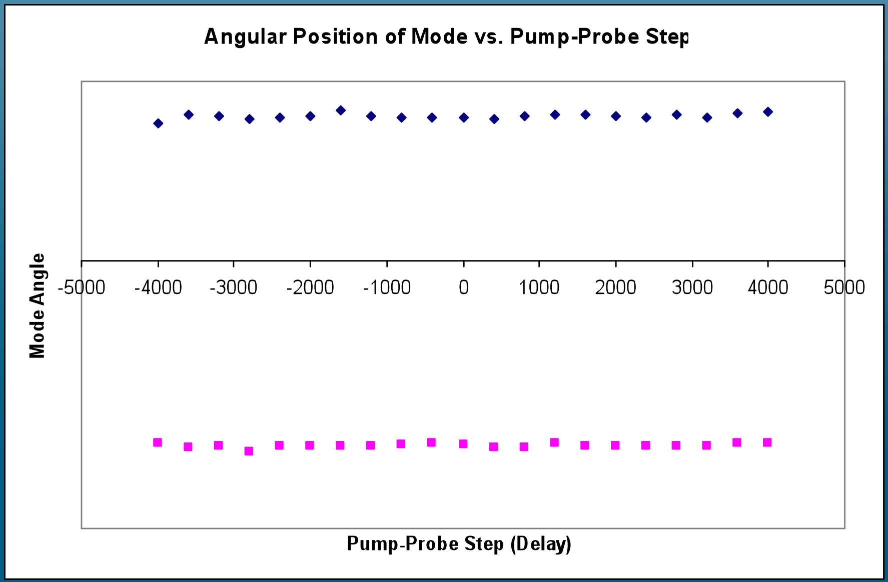
Experimental Results

- Prism coupling techniques successful for calculation of linear refractive indices and thicknesses for each of the five thin films
- Films deposited at higher oxygen pressures are thinner and thereby exhibit fewer mode angles



Deposition Pressure (mTorr)	*n*	Number of Clear Mode Angles
50	2.5526	5
150	2.5483	4
250	2.5327	3
350	2.5304	2
450	2.4906	2

Experimental Results



- Nonlinear prism coupling of TE-mode (pump) and temporally shifted TM-mode (probe) pulsed beams has proven inconclusive
- No significant shift in mode angles over range of delays tested

Conclusions

- First time method has been employed for estimation of nonlinear parameters -- experimental setup may need adjustment for proper measurement scheme
- Other proven techniques (e.g., z-scan or white-light continuum pump / femtosecond probe spectroscopy) will be employed for measurement of thin film nonlinear parameters
- Additional research will focus on improving the methodology of the current scheme for nonlinear parameter measurement

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Questions?