STRESS-INDUCED BIREFRINGENCE ANALYSIS FOR THE EFFICIENT DESIGN OF POLYMER OPTICAL WAVEGUIDE DEVICES

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Abstract

With the extension of optical communication networks to homes and other premises, studies on polymer-based optical waveguide devices have received wide interest because they are relatively easy to fabricate and permit mass production at lower costs. Polymer waveguides also have the potential to achieve low power consumption compared with conventional silica-based devices. Along with these advantages, polarization dependence has emerged as a fundamental issue in the design of waveguide-based optical devices. The polarization-insensitive operations are particularly essential for applications in optical fiber communications, as they can greatly reduce the complexity of a system. One of the important sources of polarization dependence is stress, which is generated in the waveguide unavoidably during the fabrication process. Due to stress-optic effects, the generated stress perturbs the refractive index of the waveguide material and thus makes it anisotropic (i.e., birefringent). Although it is possible to design polarization-insensitive devices by tailoring waveguide geometry, such stress-induced birefringence (if not taken into account) makes their realization complicated and inefficient. Therefore, it is important to predict the stresses in the optical waveguides, and to consider its effects in the design of a new integrated optical device. This thesis focuses on the detailed investigation of stress-induced birefringence in polymer optical waveguides and demonstrates the potential design of some basic polarization-insensitive waveguide devices in relation to stress-induced effects.
The thesis begins with the determination of elastic-plastic properties of various polymers (BCB, epoxy UV11-3 and 3505) using the nanoindentation technique. The optical waveguides analyzed in this paper consist of the said polymer materials. The determined material properties are required for the stress analysis. To predict the waveguide stresses accurately, a more realistic process-modeling framework is developed in the finite-element (FE) analysis program. The developed model can incorporates important stress build-up processes, such as polymerization shrinkage, stress relaxation, and etching, over the entire history of the waveguide fabrication process. In order to validate the stress analysis model, stresses are measured for BCB thin film waveguides, and compared with the results of the process modeling.

To obtain the effect of stress on the refractive index of waveguide material, stress-optic coefficients of the polymers used are determined. In doing so, this work presents a simple method that can measure simultaneously the stress-optic and thermo-optic coefficients of thin film waveguide using a prism coupler technique. The stress-induced characteristics are investigated thoroughly for various waveguide structures, including planar (slab), strip, and rib waveguides. The characterization of BCB planar waveguide involves both experimental and numerical techniques. The potential applications of the findings are discussed in the context of an optimized design for polarization-insensitive optical waveguide devices. The analyses of channel waveguides (strip and rib) are based on numerical simulation, as stress cannot be measured in a tiny optical waveguide. Simulation results show that significant amount of stress-induced material birefringence remains in the waveguide even after etching, although most of the stresses relax in the fabrication process. The influence of waveguide geometry (height, width, etching depth, etc.) on the stress-induced birefringence is investigated.
and presented in a generalized form, which can then be applicable for other polymer materials.

The potential of this work is demonstrated through the design of a number of zero-birefringence waveguide devices, including strip and rib waveguides, and a Bragg grating filter. The design results are compared with experimental results. Highly satisfactory agreement is achieved between simulation (considering stress-effects) and experimental results; however, the results from stress-free assumption are far from agreement. These imply that our approach can provide a more accurate way for the design of polymer optical waveguide devices.

Being generic in nature, the approach described in this thesis also enables the optimized design of integrated optical devices from the standpoint of material systems, waveguide geometry, and process parameters. This thesis is expected to lay the groundwork for this effort.
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