Previous and Current Research

Research from 2001 to 2003 was performed at COVEGA Corp., under the direction of Drs. William K. Burns and Ganesh Gopalakrishnan, and at Agere Systems / Lucent Technologies, under the direction of William J. Minford.

This work investigated critical reliability and stability issues in $LiNbO_3$ external electro-optic (EO) modulators. The research led to the development of active stability tests on finished modulators and to novel electrical measurements of their constituent materials. Two independent models were developed to explain and predict both the long-term temporal stability and thermal drift of the operational bias point.

The activation energy of the underlying drift mechanism was calculated from measurements of the modulator long-term stability over a range of temperatures. This energy was related to the measured activation energy of conduction mechanisms in the dielectric buffer layer and underlying $LiNbO_3$ substrate. Subsequently, a finite-element, electrodynamics model relating the observed drift, the geometry of the device, and the electrical and dielectric properties of the materials was developed. The model identified the conductivity of the dielectric buffer layer as the critical parameter controlling the long-term stability. As a result, a novel oxynitride layer was developed for these devices. Using reactive RF sputtering, the electrical and dielectric properties of the film could be tuned to achieve a four order of magnitude increase in device lifetime.

Thermally induced variation of the operating bias point was measured and related to processing variation in the alignment of the gold electrodes with the underlying optical waveguides. Subsequently, a finite-element model was developed to relate the thermal response to device geometry and material mechanical properties. The model was used to explain observed relationships in measured devices and to predict the sensitivity of future designs to fabrication tolerances. As a result, novel electrode designs have effectively eliminated thermally induced bias voltage drift in the current generation of $LiNbO_3$ devices.

Research from 1996 to 2001 was carried out as part of a PhD program in the Materials Science and Engineering department at Northwestern University under the direction of Prof. Bruce W. Wessels and included collaborations with Northwestern Profs. Thomas O. Mason and Prem Kumar.

This work investigated the electro-optic properties of epitaxial $BaTiO_3$ and $KTa_xNb_{1-x}O_3$ thin films to determine their utility as the active medium in future EO devices. To this end, the relationship between the EO properties, both static and dynamic, and the ferroelectric (FE) domain structure of the films was determined. The research included the development of measurement techniques for the static and dynamic EO and dielectric properties of FE thin films. To explain the resulting measurements, a theoretical model was developed to describe the magnitude and dynamic response of the EO effect and dielectric properties of multidomain FE films.

For the as-deposited, unpoled films of $BaTiO_3$ and $KNbO_3$, measured EO coefficients were more than an order of magnitude lower than in those reported for bulk materials. The lower coefficients were attributed to the multi-variant domain structure of the epitaxial films. To explain this effect, the measured linear EO coefficient of each film was successfully modeled as a linear superposition of the EO response of each FE domain variant. The model identified two mechanisms for increasing the measured EO coefficients, application of a DC poling field to preferentially align the FE domains and the rotation of measurement fields to the <110> direction of the underlying MgO substrate. Using these two approaches, measured EO coefficients in the $BaTiO_3$ and $KNbO_3$ films were increased by two orders of magnitude. Furthermore, the measurements and modeling were used to successfully explain the observed in-plane EO anisotropy and hysteresis of the dielectric and EO properties.

The measured dynamic EO response of the FE films was modeled by a statistical distribution of domain relaxation times. The transient response of EO, polarization, and dielectric measurements was described by a power law extending from ≤6 ns to 1 s in both the $BaTiO_3$ and $KNbO_3$ film systems. This non-exponential relaxation was attributed to the reorientation of FE domains using the theoretical model.