INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Harnessing Epsilon-Near-Zero (ENZ) effect in Nanophotonic Metamaterials for Modulation of Optical Intensity and Polarization

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SHORT ABSTRACT

The advancement of photonic technologies has led us to achieve active control of electromagnetic properties (viz. amplitude, phase, and polarization) of light. The active manipulation of reflected or transmitted light can be done under the influence of external stimuli such as electrical biasing (electro-optic modulation) or optical pumping (all-optical modulation). However, conventional free-space modulators are bulky due to the limitation of optical properties of naturally existing active materials used for modulation, and thus, not suitable for nanophotonic applications.

The challenges posed by the large footprint of the traditional optical modulators motivated us to explore ultra-compact alternative nanophotonic devices based on artificially-engineered materials or ‘metamaterials’. In last few years, tunable metamaterials have emerged as a potential candidate to realize ultra-compact nanophotonic free-space optical modulators, due to their capabilities to control light–matter interactions at a scale smaller than to the wavelength of light by engineering meta-atoms. Extensive research has been carried out to demonstrate metamaterial based modulators by incorporating numerous active materials, where transparent conducting oxides (TCOs) have gained ample attention due to their exceptional electro-optic properties at the telecom wavelength region. By tuning the optical properties of TCOs, we can exploit an exciting phenomenon named as ‘epsilon-near-zero (ENZ) effect’, where the real part of permittivity becomes vanishingly small at a certain wavelength.

The ENZ-effect can be exploited at the telecom wavelength regime by accumulating the free-carriers of TCOs while configured in a metal-oxide-semiconductor type structure, where strong light–TCO interactions can be seen due to the enhancement of the electric field. The variation of optical properties using electrical biasing opens the doors to design electro-optic intensity and polarization modulators for nanophotonic applications. On the contrary, upon applying optical pumping, intraband electronic transition-induced nonlinear-effect in ENZ-materials enables the realization of all-optical modulators. In this dissertation, the opportunities and challenges towards achieving efficient electro-optic and all-optical modulation have been presented for various nanophotonic applications by leveraging the ENZ-phenomenon of TCOs integrated with several resonating metamaterials.