Electro-optic modulator based on a metal-ferroelectric nanocomposite

The requirement of fast and high information rate communication necessitates new revolutionary devices for replacement of conventional devices. Transmission of electronic signals at light speed using thin-film electro-optic light modulators offers advantages of high date rate, low power consumption, low drive voltage, low cost, and integrate-ability with other active semiconductor devices. Our device modulates light at the visible spectrum by incorporating metal nanoparticles (NP) embedded within a ferroelectric (FE) thin-film. Noble metal NPs support local surface plasmons (LSPs) at optical frequencies. The frequencies and intensities of LSP resonances are known to be extremely sensitive to the dielectric properties of the surrounding medium, and in particular, to the refractive index of matter close to the particle's surface. Lead zirconate titanate (PZT) is a FE material known for its strong electro-optic effect. We take advantage of the electro-optic effect by varying the PZT polarization with an external electric field, which produces a change in the refractive index of the ceramic matrix. Consequently, metal NPs embedded in PZT thin-film will exhibit a change in their absorption and scattering properties as well. Therefore, the amplitude of light passing through the thin-film can be controlled by the external electric field. By merging the electro-optic property of FE thin-film with the LSP phenomena of metal NPs, we achieve control over the optical properties of the metal-dielectric nanocomposite. We found that on resonance embedded Au or Ag NPs can attenuate the incoming radiation through a 1 *μm* thick thin-film, by 4.42 and 12.74 *dB*, respectively. These values are achieved for an extremely small shift in the refractive index of the thin-film, *i.e.* Δn=0.005. The modulator is illustrated in figure 1.

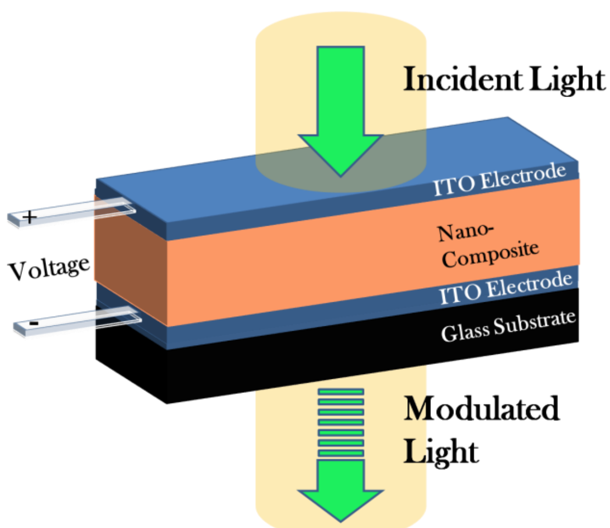

Figure 1. The layers comprising the optical modulator; light enters the device at the top, at the same time external voltage controls the refractive index. As a result, the embedded NPS LSP resonance shifts.

The optical contrast of the nanocomposite can be computed as a function of the applied voltage. Figure 2 depicts simulation results of the optical contrast of silver NPs embedded in a PZT thin-film with thickness of 1 *μm*, incidence by light with a wavelength of 575 *nm*, under 5 and 25 voltage.

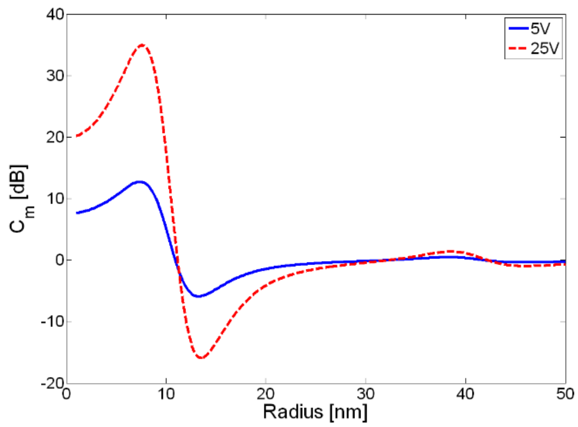

Figure 2. Optical contrast of silver nanoparticles in a PZT matrix, incidence wavelength 575*nm*, particles concentration 5%; the optical contrast is illustrated for an electrostatic field produced by a 5*V* voltage (solid) and 25*V* (dashed)

We are currently fabricating a prototype of the device with the aid of the Materials Research Institute at Pennsylvania State University (PSU). Co-sputtering preliminary results show that obtaining NPs as small as 5 nm in diameter over PZT substrate is possible, see figure 3.

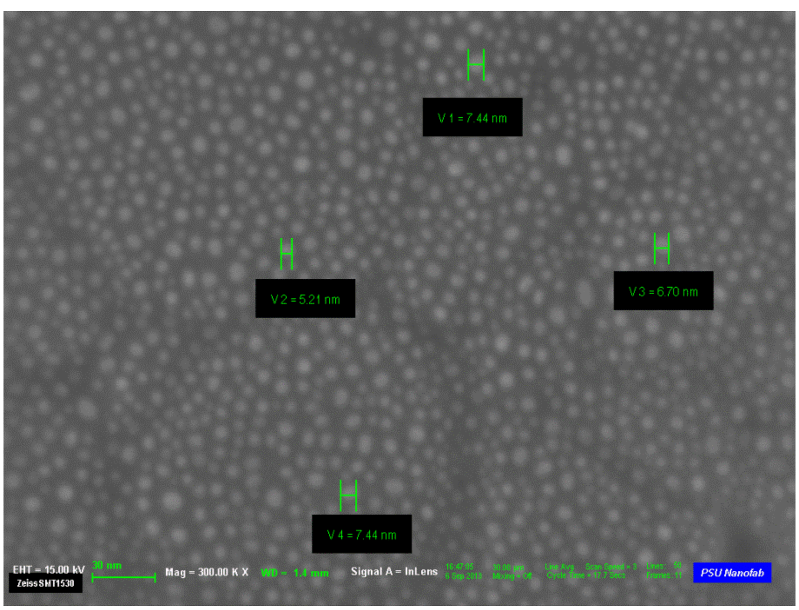

Figure 3. SEM image of Au NPs on top a PZT substrate, fabricated by co-sputtering technique. Image courtesy of PSU Nanofab.