Atomic layer engineering of epsilon near zero ultrathin films with controllable zero index field enhancement

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Enhanced and controlled light absorption as well as field confinement in an optically thin material are pivotal for energy efficient optoelectronics and nonlinear optical devices. Highly doped transparent conducting oxide (TCO) thin films with near-zero permittivities, in their so-called epsilon near zero (ENZ) frequency regions, can support ENZ modes which may lead to perfect light absorption and ultra-strong electric field intensity enhancement (FIE) within the films. To achieve full control over optical absorption and FIE, one must be able to tune the ENZ material properties as well as the film geometries.

Here, we report an nano-engineering of ultra-smooth aluminum doped zinc oxide (AZO) films with tunable ENZ wavelength (1500-1725 nm), low optical losses, and thickness as small as 22 nm by using atomic layer deposition (ALD) technique. The ENZ properties of the AZO thin films are controlled by deposition conditions such as dopant ratio, deposition temperature, and number of macro-cycles. We experimentally demonstrate engineered absorption and FIE of AZO thin films via control on their ENZ wavelengths, optical losses, and film thicknesses. Furthermore, we introduce a simple mathematical formula for quick and accurate estimation of FIE when ENZ modes are excited in classical Kretschmann-Raether configuration. Finally, we demonstrate that under ENZ mode excitation, though the absorption and FIE are inherently related, the film thickness required for observing maximum absorption differs significantly from that for maximum FIE. This systematic study on engineering ENZ materials related enhancement properties by optimization of ALD deposition process will be beneficial for the design and development of next generation tunable photonic devices based on flat zero-index optics.