Broadband and Gate-Tunable Conducting Oxide Epsilon-Near-Zero Perfect Absorber

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Abstract: We demonstrate broadband and gate-tunable conducting oxide epsilon-near-zero perfect absorbers grown by atomic layer deposition. Absorption bandwidth (> 90%) of 214 nm for Berreman mode in NIR region is realized.© 2018 The Author(s)

Epsilon near zero (ENZ) materials (material with near zero permittivity) have drawn much attention due to their unique optical functions such as non-reciprocal magneto-optical effects, tunneling of electromagnetic wave, and abnormal nonlinearity [1, 2]. Highly doped transparent conducting oxides (TCO), such as Al-doped ZnO (AZO) and indium tin oxide (ITO), is an example of the ENZ materials. Recent studies indicate that broadband and perfect ultrathin film absorbers can be fabricated using TCO materials [3-6]. In this work, we first demonstrate a broadband AZO absorber by stacking AZO nanolayers with different electron concentrations and ENZ frequencies, and then show a gate-tunable ITO perfect absorber with ultrathin thickness (~λ/100).

Berreman mode [7] can be excited with a p-polarized (TM) light incident on ENZ film at an angle in configuration shown in Fig. 1(a), in which BK7 glass works as incidence medium backed by three AZO layers with different electron concentrations on top of a thick gold reflector. Three AZO nanolayers are grown by atomic layer deposition (ALD) which can conformally deposit ultrathin films with good uniformity and surface smoothness [8]. The AZO layers have zero permittivity at 1497 nm (AZO_1), 1571 nm (AZO_2), and 1700 nm (AZO_3), which was measured by ellipsometry. The AZO thicknesses of the broadband perfect absorber are optimized at a fixed angle of incidence of 43°. The optimized thicknesses are 80, 60, and 50 nm for the bottom (AZO_3), central (AZO_2) and top (AZO_1) layers, respectively. The simulated and measured absorptance are shown in Fig. 1(b)(c). The perfect absorption (dark blue) occurs around 1300 nm which is in a good agreement with the simulated results. The absorption bandwidth (>90%) of 214 nm in NIR region is realized.

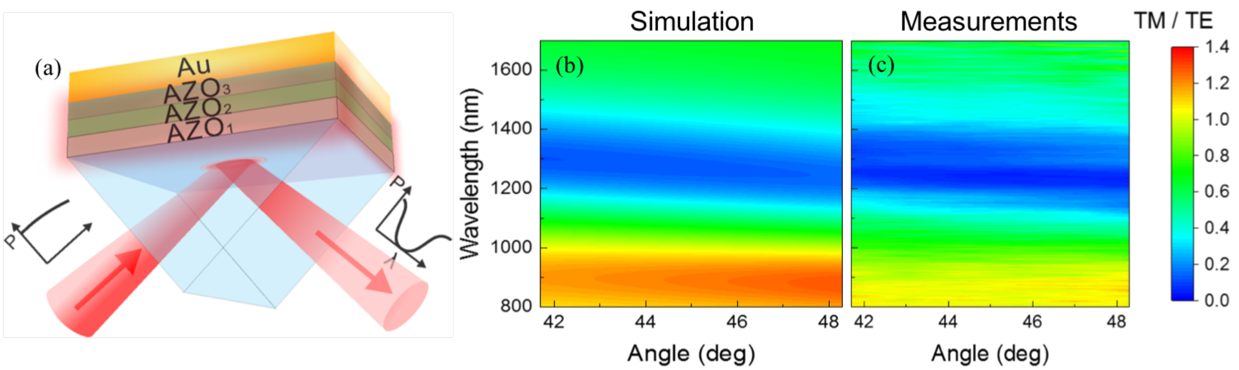

Fig. 1. (a) Schematic of the Berreman mode excitation in AZO multilayer. AZO_1 = 50 nm AZO_2 = 60 nm AZO_3 = 80 nm. (b) Simulated ratio of TM/TE reflectance spectra. Perfect absorption (dark blue) occurs around 1300 nm. (c) Experimentally measured ratio of TM/TE reflectance spectra, showing a good agreement with simulated ratio in (b).

For a single layer perfect absorber, the thickness of TCO layer could be ultrathin and comparable with the Debye length of the common field-effect devices, which makes it possible to electrically tune the perfect absorption wavelength by applying external bias. In the second part, we demonstrate a gate tunable ultrathin ITO perfect absorber shown in Fig. 2(a). The ITO thickness is 4 nm. The background doping concentration is $n = 2\times10^{21}$ cm^{-3} and the electron density near the HfO_2-ITO interface is plotted in Fig. 2(b). Depletion and accumulation are formed at 0 V and 5 V respectively, which leads to a significant change in the absorptance shown in Fig. 2(c). In order to achieve perfect absorption, TiO_2 (rutile) is selected as the incidence medium. Vertical dotted line shows ENZ wavelength of 752 nm. Insets show the absorptance difference in %. The perfect absorption wavelength shifts of 20% of full width at half maximum (FWHM) and the absorptance changes of around 150 % are observed under the bias of 5 V.

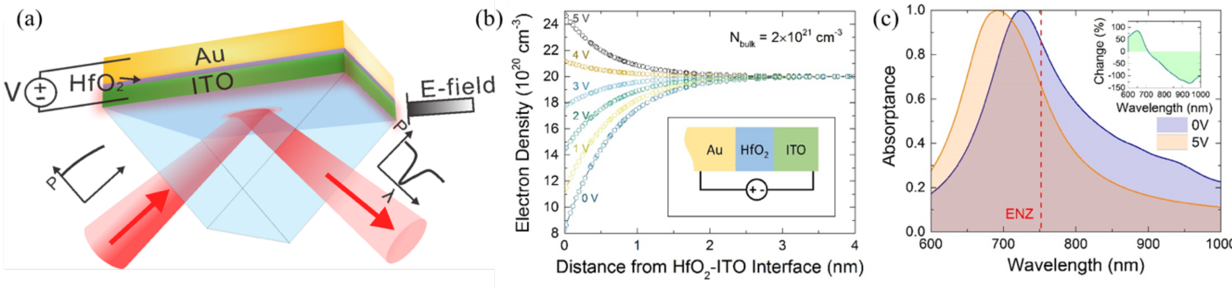

Fig. 2. (a) Schematic of the Berreman mode excitation in single ITO layer. (b) Electron concentration at the HfO2-ITO interface at applied bias of 0-5 V. Inset shows a schematic of the simulated MOS field-effect perfect absorber. The hafnium dioxide thickness is 5 nm and the bulk electron concentration of ITO is $n = 2\times10^{21}$ cm^{-3}. (c) Perfect absorption tuning: absorptance of the unbiased and 5V-biased MOS field-effect perfect absorber at the incidence angle of 60°.

In conclusion, we experimentally show a broadband AZO absorber by stacking three AZO nanolayers. The absorption bandwidth (>90%) of 214 nm in NIR region is shown. We also demonstrate a gate tunable ITO perfect absorber with perfect absorption wavelength shifts of 20% of FWHM and the absorptance changes of around 150 % under the bias of 5 V.

Acknowledgments

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