Supporting Information: Extremely subwavelength metal oxide direct and complementary metamaterials

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KEYWORDS metamaterials; metasurface; plasmonics; split ring resonator; transparent conducting oxides; indium tin oxide.

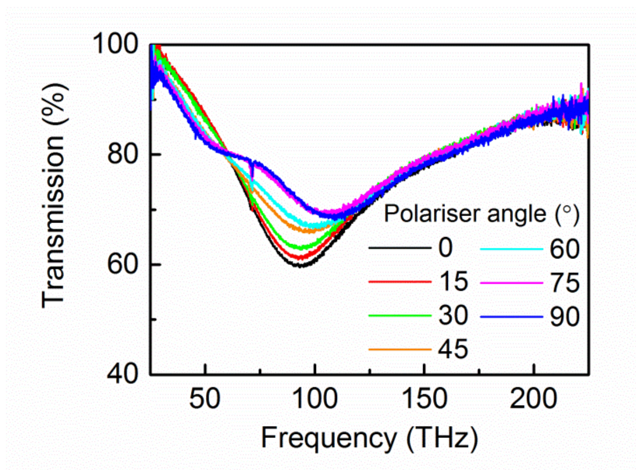

Figure S1. Transmission through a direct ITO metamaterial array *w* = 400 nm, *a* = 850 nm, where 0° corresponds to TE polarization and 90° to TM.

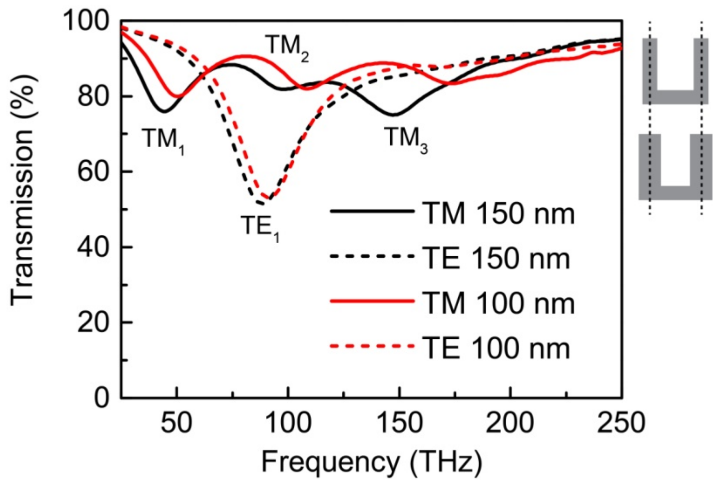

Figure S2. Simulated resonant response of metamaterials with different arm thicknesses made from an ITO-like Drude material (N=1.4 ×10^{21} cm^{-3}). For 50% thicker SRR arms, the TM_1 and TM_2 modes are shifted by less than 10%, and the TE_1 mode is even less affected. However, the higher order TM modes seem more sensitive to the variation. Therefore, variation in SRR arm width accounts for the absence of clear higher order modes (e.g. TM_3).

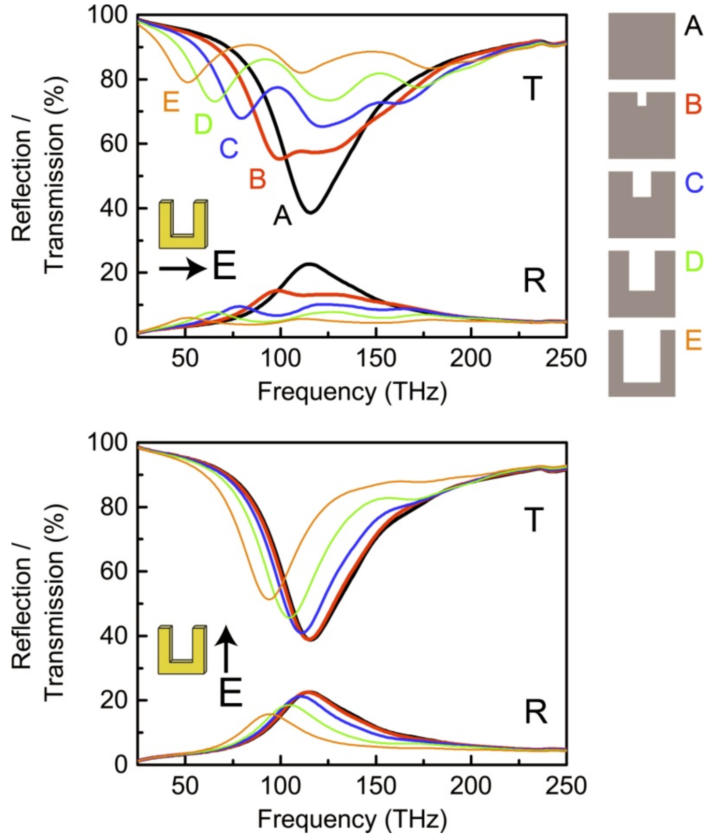

Figure S3. Simulated resonant response of metamaterials with different degrees of development from a square (A) to a fully developed U-shape (E). The metamaterial was made from an ITO-like Drude material (N=1.4 $\times 10^{21}$ cm^{-3}). The simulated TM spectra show a continuous transition from a single electric mode to a number of magnetic modes (TM_1 - TM_3). The relative amplitudes between TM_1 and TM_2 depend strongly on the size of the center gap.

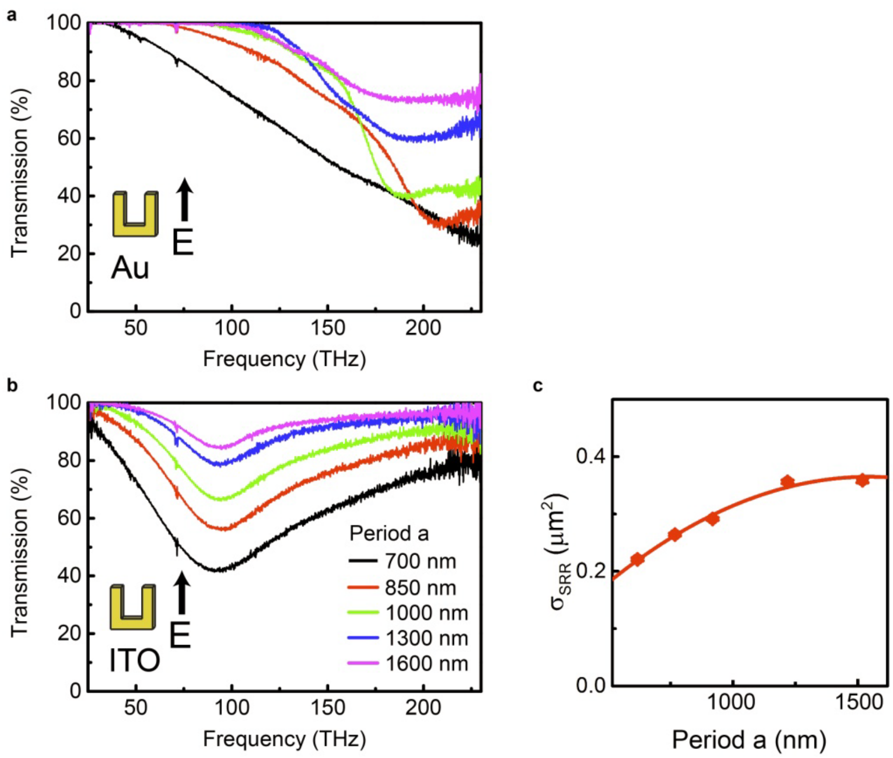

Figure S4 (a,b) Infrared transmission spectra for Au (a) and ITO (b) arrays, presenting the TE modes. (c) Calculated cross section per SRR, σ_{SRR}, for the TE_1 mode of ITO. Fit line serves as a guide to the eye.

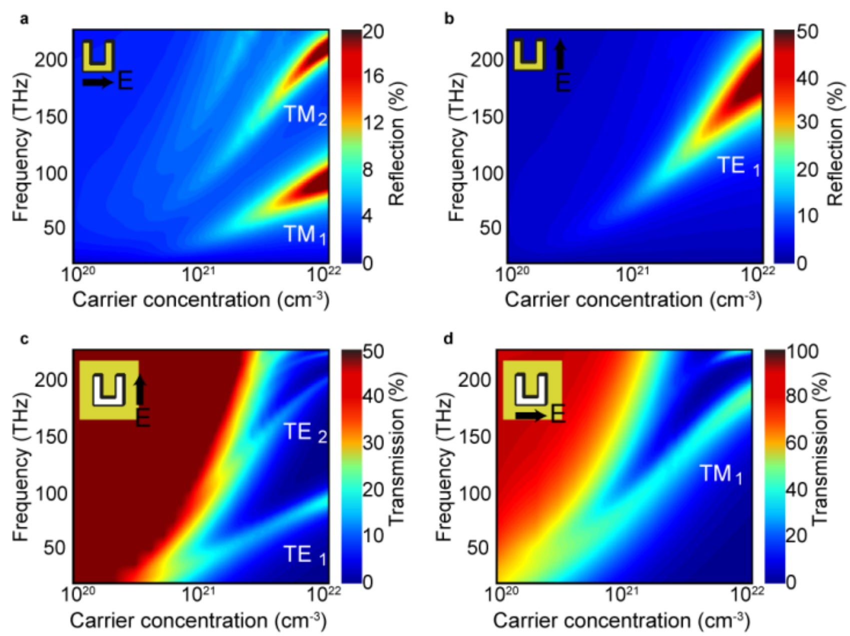

Figure S5. (a,b) Simulated spectral maps for reflection through SRR metamaterials made from a ITO-like Drude metal of varying carrier density between $10^{20} – 10^{22}$ cm^{-3}, for both horizontal (TM) and vertical (TE) polarizations. (c) Simulated spectral map for reflection from a c-SRR array of an ITO-like Drude metal of varying carrier density between $10^{20} – 10^{22}$ cm^{-3}, for both vertical (TE) and horizontal (TM) polarization.

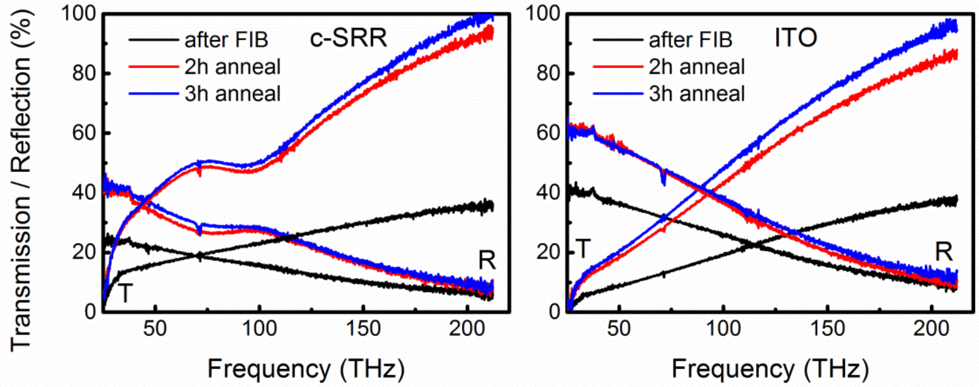

Figure S6. TE spectra of ITO and film and complementary ITO metamaterials after FIB processing for different anneal times. Metamaterial arrays correspond to the c-SRR in Figure 5(c), with L = 500 nm. After FIB processing, no resonances are observed, after annealing the plasmonic behavior is recovered. We suggest this is due to Ga^{+} ion implantation and subsequent (incomplete) removal. The changes in transmission and reflection are also seen in ITO, suggesting this effect is not localized to FIB patterned areas.