## Title

An All-Optical, Non-volatile, Bidirectional,Phase-Change Meta-Switch

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## Abstract


*Nanostructured Plasmonic Medium for Terahertz Bandwidth All-Optical Switching*
Using a *nanostructured gold film* to achieve an ultrafast resonant switch.
Based on *Fermi-smearing* and *two photon absorption*.


## Highlight

**Fermi-smearing:** process in which light absorption at a frequency $\omega_p$ leads to a non-equilibrium redistribution of electronsnear the Fermi level (EF). When probed at $\omega_s$ , this Fermi-smearing has most impact on transitions between the d-band states lying $\Delta E = 2.4$ eV below the Fermi level to states above the Fermi level. Fermi-smearing leads to a very strong cubic optical nonlinearity and nonlinear absorption ($\beta \approx 10^{-5}\,\mathrm{m\,W^{-1}}$) peaking at a wavelength of about 516 nm.

**two-photon absorption:** Direct two-photon absorption takes place without a real intermediate level as there are no empty states in the Fermi sea. It occurs through a virtual state when the energy of two incident photons is combined to bridge a gap that cannot be bridged by individual photons: $\hbar\omega_p + \hbar\omega_s > \Delta E$. When characterized in a pump–probe experiment, the direct two-photon absorption nonlinearity has a very fast response time because it requires both the pump $\omega_p$ and the probe $\omega_s$ photons to be present simultaneously, and no slow decay carrier recombination is involved. In fact the uncertainty principle prescribes a finite lifetime for the virtual level, and thus a finite nonlinearity response time of order $\hbar/\delta E < 1\ \mathrm{fs}$, where $\delta E \approx \frac{1}{2}\Delta E$ is the energy difference between the virtual level and the nearest real state. Even with this limitation, this is an extremely fast degenerate cubic optical nonlinearity giving rise to a nonlinear absorption coefficient of order $10^{-8}\,\mathrm{m\,W^{-1}}$

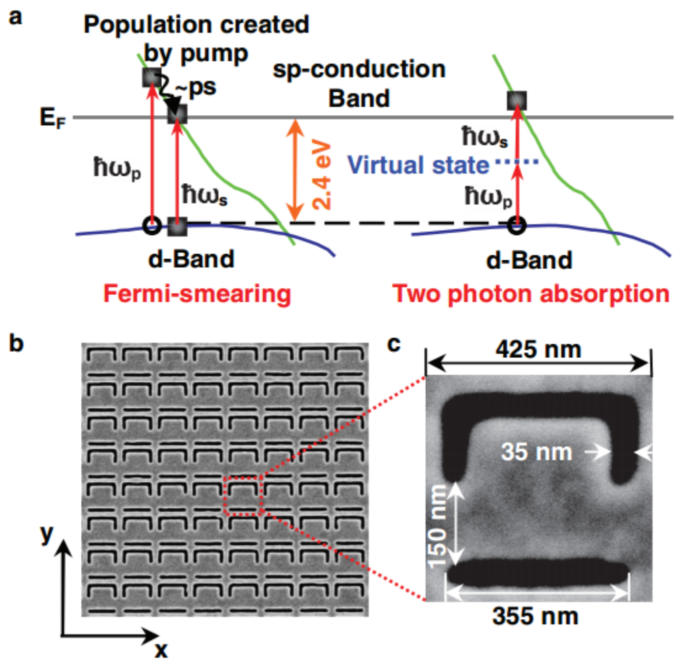


**Figure 1.** Metamaterial with giant plasmon-mediated femtosecond nonlinearity. a) Comparison between Fermi smearing and two-photon nonlinear responses in gold. b) Scanning electron microscopy (SEM) image of the nanostructured gold film. c) Detail of a single meta-molecule.

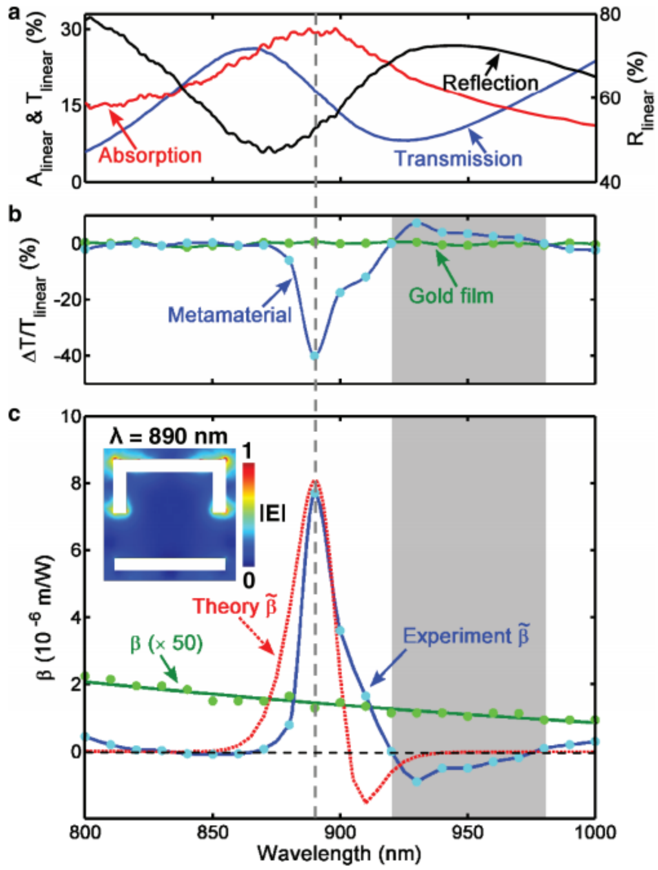


**Figure 2.** Metamaterial linear and nonlinear optical properties. a) Linear absorption, transmission, and reflection spectra of the metamaterial near its plasmonic resonance. Light is polarized in the y-direction as defined in Figure 1b. b) Nonlinear transmission change $\Delta T/T$ linear at an illumination pulse peak intensity of 2.3 $\mathsf{GW\,cm^{-2}}$ for the metamaterial and an unstructured gold reference film. c) The metamaterial's experimentally measured and theoretically evaluated effective two-photon absorption coefficient $\tilde{\beta}$ compared to that of an unstructured gold film $\beta$ (multiplied 50×). The shaded area shows the frequency range of absorption saturation. The inset shows a numerically simulated map of the electric field magnitude 10 nm below the gold surface at a wavelength of 890 nm.

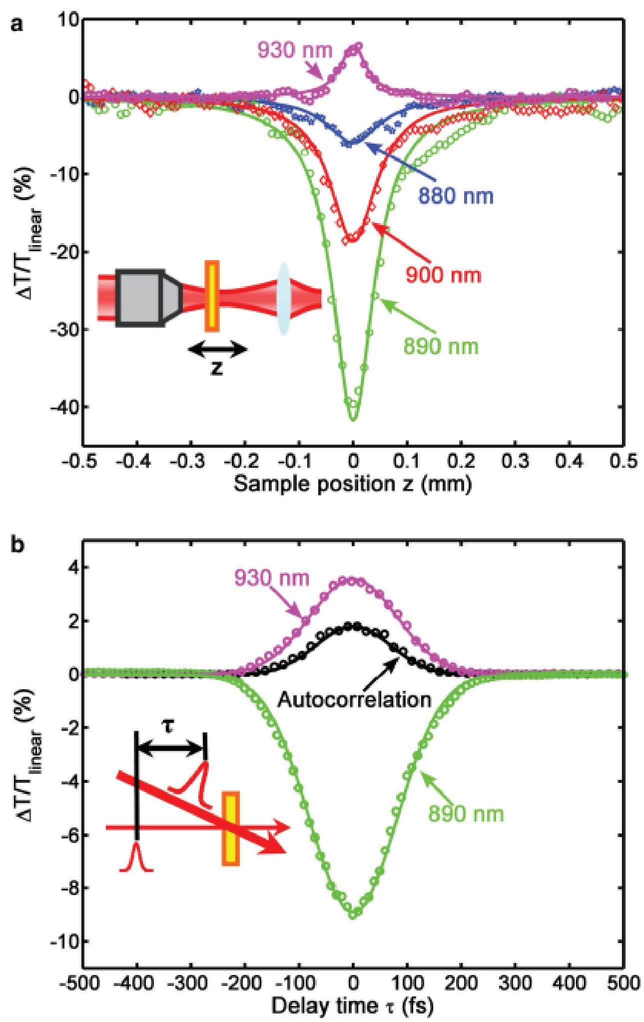


**Figure 3.** Giant ultrafast nonlinearity of a plasmonic metamaterial. a) Z -scan traces taken at an average laser power level of 3 mW (data points) with corresponding analytical fits (lines) for a selection of characteristic wavelengths near the metamaterial's plasmonic resonance. b) Time-resolved pump–probe scans showing nonlinear absorption and bleaching dynamics for the metamaterial alongside a reference second-harmonic autocorrelation envelope for the pulses.

## Related work