Nonlinear Reflectance of Planar Plasmonic Nanostructure

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Abstract: We reveal nonlinear reflectance of a planar plasmonic film with nanoaperture arrays. We further demonstrate that the nonlinear response of the plasmonic nanostructures can be effectively controlled by structural parameters.

OCIS codes: (190.4360) Nonlinear optics, devices; (240.6680) Surface plasmons; (230.4000) Microstructure fabrication

1. Introduction

Surface Plasmons (SPs) are of interests to a wide spectrum of photonic science and engineering, and have been explored in devices such as optical modulators, optical sensors, and photodetectors. Plasmonic nanostructures can excite and control SPs on the surface of noble metals, which can be used to manipulate light-matter interactions and boost nonlinear phenomena [1,2]. Due to their broadband absorption induced by SPs resonance and fast response time of few picoseconds, gold nanoparticles (GNPs) fabricated by chemical ways (GNPs were often synthesized from the reduction of $HAuCl_4$ solution [3-5]) have been widely studied as saturable absorbers for constructing all-fiber Q-switched or mode-locked lasers. For examples, gold nanorods were applied as a visible saturable absorber (SA) to enable a 635 nm Q-switched pulse fiber laser, and gold nano crystals have been successfully used for passively Q-switching at 1560 nm [3,4]. However, limited by the fabrication methods, gold nanoparticles typically exhibit large variance in their physical dimensions, making precisely control their optical properties a challenge. Traditional plasmonic nanostructures have advantages in terms of uniform and large area processing. Nonlinear properties of plasmonic nanostructure in noble film have been widely studied, such as third harmonic generation, four-wave mixing [6,7]. However, the nonlinear response in absorption remains unexplored.

Here, we for the first time reveal the nonlinear reflectance of a planar plasmonic film with periodic nanoaperture arrays. Our results show that the nonlinear response can be effectively controlled by its structure parameters, i.e. diameter and period of aperture array. Such a finding indicates plasmonic nanostructure film can be potentially used as a highly tunable saturable absorber (SA) for pulse generation applications.

2. Result and Discussion

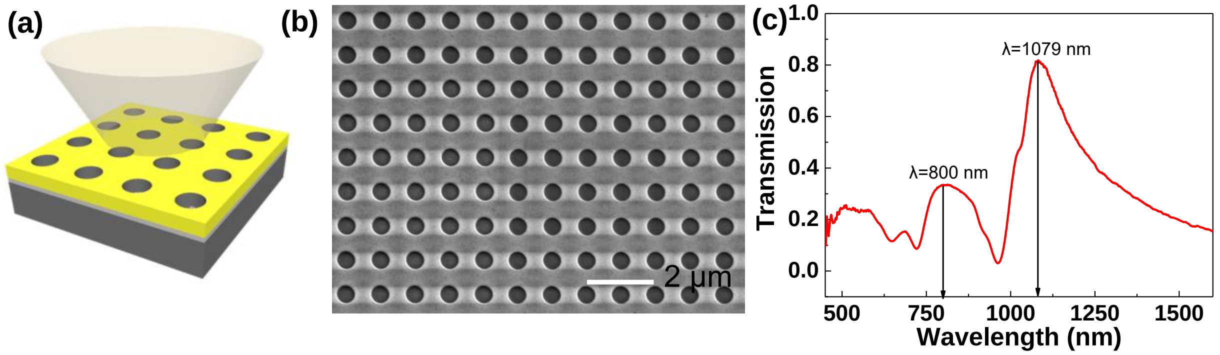

Fig. 1 (a) Schematic illustration of the planar plasmonic nanostructure. (b) SEM image of device (scale bar: 2 μm). **(c)** The transmission spectra of the planar plasmonic nanostructure.

Periodic nanoaperture arrays were etched by focused ion beam milling through an 80 nm thick gold film evaporated on a silicon wafer with a 100 nm SiO_2 film on top. Fig. 1(a) schematically shows the structure of the device. 5 nm thick titanium film was grown by electron beam evaporation, between the gold film and SiO_2 film, to enhance the adhesion between the gold film and the substrate. Fig. 1(b) shows the SEM image of the nanoaperture arrays with period of $P=1$ μm and diameter of $D=0.5$ μm. The linear spectral response of the plasmonic nanostructure was experimentally measured in a micro-photospectrometer (CRAIG), as shown in Fig. 1(c). According to this transmission spectrum, there are two obvious surface plasmon resonant peaks located at 800 nm and 1079 nm. Then, we used a Ti:sapphire laser oscillator with a wavelength of $\lambda=800$ nm to probe the one of the resonant peak of our plasmonic nanostructure.

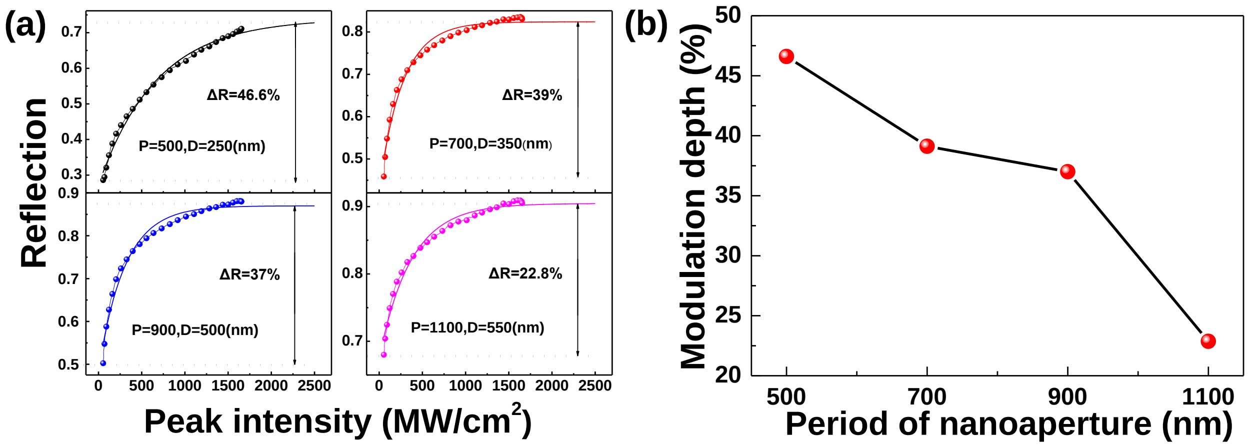

Fig. 2 (a) The nonlinear reflectance of the planar plasmonic nanostructure with different periods and diameters. (b) Modulation depth as function of the period of nanoaperture arrays.

A high precision nonlinear absorption measurement system (all experiments were performed using 200 fs pulses at 800 nm from a mode-locked Ti: sapphire laser) is performed to investigate the nonlinear reflectance of the planar plasmonic nanostructure [8]. The nonlinear reflectance curves of the planar plasmonic nanostructures are shown in Fig. 2(a). It is clearly shown that the reflectance of the devices increases with peak intensity of the laser, and can be saturated as the intensity reaches GW/cm^2 level. By fitting the data shown in Fig. 2(a) with equation $\alpha(I)= \alpha_s/(1+I/I_s)+ \alpha_{ns}$ ($\alpha(i)$: absorption coefficient; α_s: saturable absorption; α_{ns}: nonsaturable absorption, I_s: saturable intensities), we find that the modulation depth (ΔR>20%) of planar plasmonic nanostructure is, generally speaking, larger than gold nanorods (ΔR~10%) or gold nano crystals (ΔR~16%) [4,5], and so it is with the saturable intensity(I_s). We attribute the observed nonlinearity to SPs resonance, as observed in gold nanoparticles [4-6]. Furthermore, we find that the saturable absorption of the planar plasmonic nanostructure can be effectively modulated by its structure parameters. The modulation depth of the planar plasmonic nanostructure can be tuned from 46.6% (P=500 nm) to 22.8% (P=1100 nm). The tunability of the modulation depth is illustrated in Fig. 2(b). Pulse generation experiment in a fiber laser using the devices as nonlinear reflective mirrors is currently underway.

3. Conclusion

In summary, we have for the first time investigated the nonlinear reflectance of planar plasmonic nanostructure with periodic nanoaperture arrays. In addition, the experimental results show that the nonlinear response of the planar plasmonic nanostructure can be effectively tuned by modulating parameters of the device structure. Our research may provide a new way to fabricate novel saturable absorption mirror for ultrashort pulse generation.

5. References

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