Large Reversible Plasmon Shift with Au Nanodisc Dimers on Thin film VO_2

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Abstract: By coupling Au dimer nanostructures to an underlying thin film of phase change material, vanadium dioxide, significant shifts in the plasmonic scattering spectra are observed, allowing for dynamic tuning within the visible spectral range.

Over the last two decades much research has been done on the use of plasmonic nanostructures and metamaterials for nanoscale control of electromagnetic radiation. The spectral response of single nanoparticle structures and periodic arrays of nanoparticles is highly sensitive to factors set during fabrication, such as structural dimensions and material composition. Despite the wide range of applications in various optical systems the inability to dynamically tune the response of these structures post-fabrication is a limitation for many possible applications. To overcome this, we present tunable plasmonic elements consisting of plasmonic nanoparticles on top of a thin film of phase change material vanadium dioxide (VO_2). VO_2 is an attractive material option due to its large, reversible transition from a semiconducting phase to metallic phase at a critical temperature of 68°C [1], significantly closer to room temperature than rival phase change materials GST or AIST. In addition to the thermal actuation of the VO_2 phase change, the phase change can be electrically or optically driven. Voltage sweeps on thin films of VO_2 indicate a threshold field of 2.8×10^6 V/m, significantly lower than GST (5.6×10^7 V/m) [2] and AIST (1.9×10^7 V/m) [3] indicating decreased power consumption in switching VO_2 based devices.

Much of the previous research involving VO_2 has focused on the relatively large changes in its optical properties in the NIR and IR ranges (> 1 μm) due to the phase transition. Changes around the visible region are pronounced enough to induce significant shifts in the spectral response of coupled nanoparticles [4]. In this work we exploit these changes in the dielectric function at visible wavelengths to manipulate the position of metallic nanoparticle plasmon resonance features. Through numerical simulations, the impact of VO_2 thickness and nanoparticle size and material on the scattering spectra in both VO_2 phases is investigated. The wavelength shift ($\Delta\lambda$) seen between these phases is used to evaluate structure suitability for applications in optoelectronics. Single nanoparticles discs, rods, cuboids and disc-based dimer structures were investigated to determine the largest shift in plasmonic response. Nanoparticles with anisotropic dimensions were selected to allow for the excitation of plasmon resonances along the longitudinal and transverse axis. Herein we present reversible large shifts for nanodisc dimer structures on thin film VO_2. Significantly, plasmon peak wavelength shifts of ~600 nm can be seen for a dimer structure with a disc radius of 90 nm on a 200 nm VO_2 thin film.

Numerical simulations of Au disc dimer structures on thin film VO_2 were carried out for a range of dimers with radii between 40 and 90 nm. VO_2 thicknesses of 10, 30, 50, 100, 150 and 200 nm were selected to investigate the impact of the VO_2 layer on the plasmonic response of the dimers. This investigation was performed for a fixed dimer height of 40 nm and a gap size of 10 nm, a configuration that can be easily fabricated using standard electron beam lithographic methods.

The scattering spectra shown in Fig 1 (b) and (c) are calculated by averaging the response along the dimer axis and off the dimer axis. From Fig 1 (b) it can be seen for a structure with disc radius 45 nm the blueshift increases significantly with increased VO_2 thickness, as in the high temperature metallic phase the resonance feature remains around 780 – 800 nm while in the low temperature the resonance feature redshifts over 130 nm. This trend can similarly be seen in Fig 1(c) where increasing disc radius redshifts the response significantly in the metallic phase while only marginally shifting the response in semiconducting phase. Table 1 summarises the shift in response between the two phases and indicates a larger plasmonic particle coupled with thicker VO_2 will maximise the shift in wavelength. It's noted that the resonant features in the semiconducting phase are quite broad when compared to similar features in structures such as cuboids. Additionally, while this broad feature gives a large wavelength shift amplitude in the IR region, 50 nm VO_2 thin films offers the largest scattering increase near the visible region.

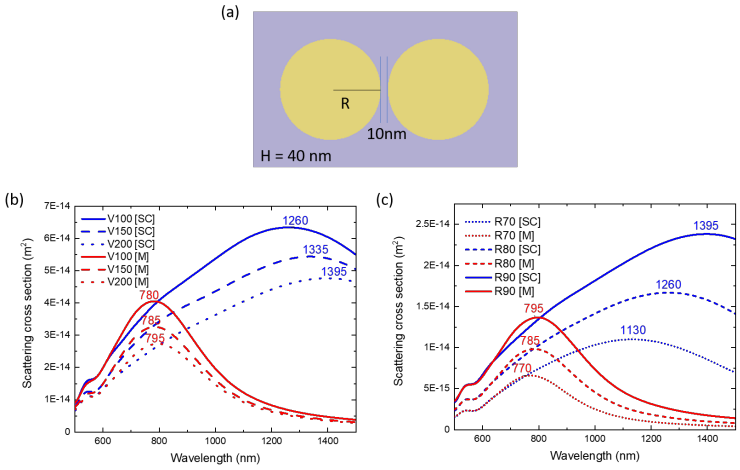

Fig. 1(a) Schematic of the Au dimer nanodisc structures on VO_2 dimer gap = 10 nm, radius R, and disc height, H = 40 nm (b) Scattering spectra for nanodisc dimer structures (radius = 90 nm, height = 40 nm, gap = 10 nm) on VO_2 of thicknesses 100,150 and 200 nm in both semiconducting (blue lines) and metallic phase (red lines) (c) Scattering spectra for nanodisc dimer structure (height = 40 nm, gap = 10nm) with radii of 35,40 and 45 nm on VO_2 (thicknesses = 200 nm) in both semiconducting (blue lines) and metallic phase (red lines).

Table 1. Au Dimer Δλ

	V10	V30	V50	V100	V150	V200
R20	60	100	105	105	115	115
R25	85	135	140	155	165	180
R30	110	190	200	215	240	255
R35	145	260	275	290	330	360
R40	180	345	390	385	440	475
R45	240	435	510	480	550	600

Table 1. Shifts in the peak scattering wavelength when the VO_2 thin films transitions between its two phases for dimers of various radius and VO_2 of various thicknesses. The table indicates an increase in Δλ for increasing dimer radius and VO_2 thin film thickness.

In our system of plasmonic dimer structures, upon the VO_2 phase change, a blueshift of scattering peak wavelength of up to 600 nm can be seen. It's noted that while the increased VO_2 thickness gives a larger Δλ a damping effect can also be seen resulting in lower scattering amplitude, this is mitigated somewhat by the increased magnitude from larger dimer structures. These reversible wavelength shifts are significantly larger than any previously reported and therefore this system is an interesting candidate for applications where dynamic tuning of the plasmon spectral features is required.

Acknowledgements
This research was funded by Science Foundation Ireland under grant number SFI under Grant number 16/IA/4550.

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