Ultrafast beam steering of photoluminescence from dielectric metasurfaces

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Abstract: We demonstrate ultrafast (<200 fs) unidirectional steering of photoluminescence over a 60° field of view from dielectric metasurfaces with embedded InAs quantum dots by creating a dynamical index grating using structured illumination.

1. Introduction

The ability to achieve solid-state dynamic beam steering is of critical importance for several applications including Lidars, free-space communications, and the defense industry. The emerging field of reconfigurable dielectric metasurfaces – made of nanoscale dielectric meta-atoms - have shown great promise in achieving this through sub-wavelength control of the phase, amplitude, and polarization of light [1,2]. These active metasurface demonstrations have been limited to manipulating coherent light sources (lasers) which help the metasurface resonators to phase-lock with each other. In this abstract, we demonstrate active and ultrafast steering of photoluminescence (PL) from epitaxial InAs Quantum dots embedded in semiconductor metasurfaces by shaping the spatial refractive index pattern through structured illumination from a strong optical pump.

2. Results and Discussion

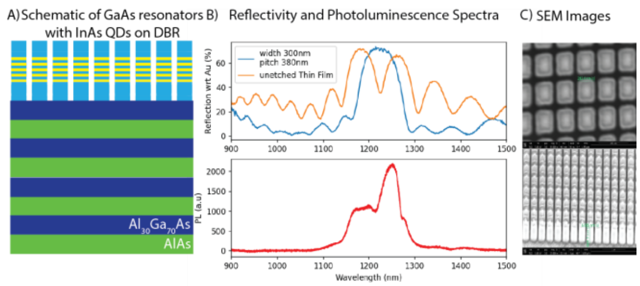

Figure 1. A) Schematic of the GaAs metasurface containing InAs QDs embedded inside $In_{0.15}Ga_{0.85}As$ quantum wells grown on a DBR stack using Molecular beam epitaxy on GaAs wafer. B) Reflectivity (top panel– blue curve: metasurface and orange curve: as grown wafer) and metasurface PL (bottom panel red curve) spectra measured. C) The top panel shows the top-down SEM of the metasurface (of side 300nm with a pitch of 380nm) and the bottom panel showing the height of 665nm for the

Dielectric metasurfaces with embedded emitters have demonstrated extraordinary capabilities to enhance the Purcell factor and control the far-field emission patterns of PL [3,4,5]. Here, (Fig 1) we employ a metasurface consisting of GaAs meta-atoms with embedded InAs quantum dots grown on top of a reflective DBR substrate to actively steer the emission using a dynamic refractive index profile generated through structured illumination. We demonstrate fs-temporal evolution of the PL in the back-focal-plane (BFP) using a 2-color (800nm and 950nm) pump scheme (Fig 2a). A refractive index spatial grating is impinged onto the metasurface using a strong optical pump (800nm, 200fs, 1kHz rep. rate, 1mJ/cm^2 per pulse) in combination with a spatial light modulator. The probe pulse at 950nm (which selectively optically pumps the QDs but not the GaAs resonators) is generated using an OPA followed by SHG using a BBO crystal (200fs, 1kHz rep. rate, 1uJ/cm^2 per pulse). This two-color experiment constitutes a variant of a PL correlation experiment [6] and enables us to understand the temporal dynamics when these two fs-pulses overlap on the sample. The 800nm pump beam is spatially structured using a spatial amplitude profile corresponding to a blazed grating (with positive and negative slopes); this spatially structured pump then creates a grating-like pattern of free carriers which then (Fig 2B) translates into a spatially varying refractive index profile superimposed on the metasurface; we estimate an index modulation of $\Delta n \sim 0.5$ at 1250nm based on the Drude dispersion of the free carriers ($\sim 10^{20} cm^{-3}$) in the GaAs meta-atoms. This pump-induced index grating adds a unidirectional momentum to the intrinsic far-field emission profile of the metasurface. The same pump along with the probe beam photo-excites the QD layers in the meta-atoms and creates PL in the 1225nm spectral range. The measured signal detected at the sum frequency of the frequencies used to chop the individual beams is normalized over the field of view for every pump pattern. The far-field directionality of the PL from the InAs QDs reflects the modification of the light density of states caused by the pump induced local changes in the refractive index.

We demonstrate that the PL can be unidirectionally steered over a 60° field of view (only limited by the collection optics) based on the pump induced grating. The momentum resolved temporal evolution of the PL for positive and negative (±25) grating orders (Fig 2C) demonstrates that we can steer the light into different directions at fs-time scales using different pump patterns. Additionally, the onset of the steering follows the temporal evolution of absorption of the pump; our 2-color pump experiment shows the temporal evolution of the PL during the temporal

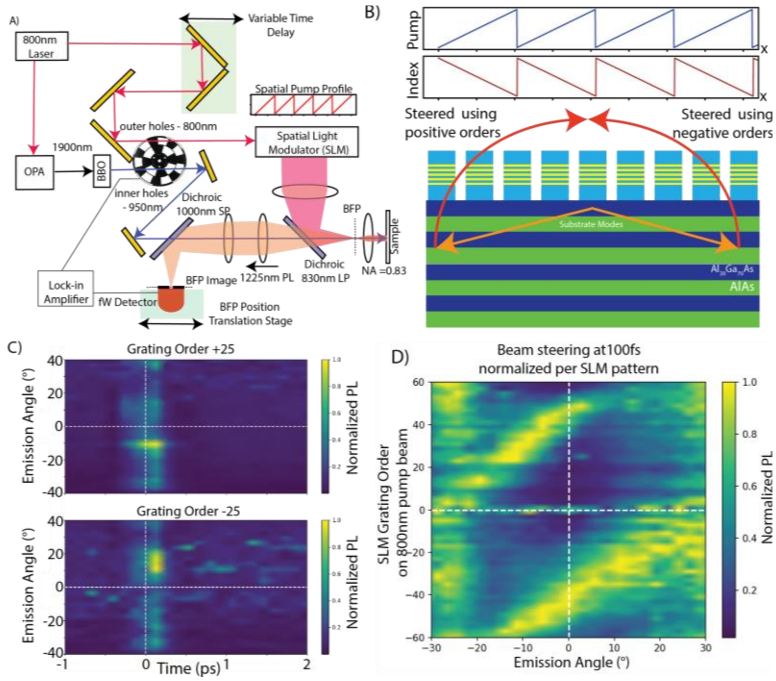

Figure 2 A) Two color pump experimental lock-in detection setup for BFP PL measurement. The measured signal detected at the sum frequency of the frequencies used to chop the individual beams is normalized over the field of view for every pump pattern. B) Sketch demonstrating the operational principle of beam steering - the spatial optical pump profile gets translated into a spatial refractive index profile on the metasurface which ultimately steers the modes in the substrate into free space through momentum matching. C) Time domain BFP plots of PL under different illumination conditions of the SLM (±25 grating orders) demonstrating fs-steering of the emitted light. D) PL steering demonstrated in the BFP as a function of different pump grating profiles at T_0. The positive grating orders steer the light from -30° to 10° while the negative grating orders take the emitted light from +30° to -15°.

overlap between the pump (800nm) and the probe (950nm). We plot the measured PL in the BFP normalized per SLM pattern at a fixed time delay of 100fs (Fig 2D) to demonstrate the steering of the PL. There are 2 distinct emission lobes for the positive blaze gratings and negative blaze gratings each. The intrinsic emission directions defined by in the local density of states (LDOS) of the metasurfaces are steered by momentum matching to the pump induced grating. An unpatterned (flat) pump profile would excite 2 beams (orange arrows in Fig 2B) from a uniform array of nano-pillars [4] at symmetric directions away from the normal (0°). These emission lobes are steered (along the red curved arrows) using the SLM pump where only one of these beams are in the field of view for a given grating order.

In conclusion, we have shown fs PL steering from light emitting dielectric metasurfaces using a 2-color pump experiment. The grating on the pump leads to a spatial refractive index profile on the sample which dynamically steers the far-field PL from the QDs embedded in the meta-atoms. The results demonstrate that incoherent PL can be dynamically steered at femtosecond-time scales using structured illumination from an optical pump.

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3. References

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