Optical Metasurfaces for Étendue Reduction In Wireless Communication

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The conservation of the étendue of light sources, defined as the product of the source's area by the solid angle of the emission, by optical components, sets a limit on how well the emission from a large area and bright source can be focused. Focusing on small areas is crucial for a fast optical detection due to the reduction of the response time of photodetectors by the residual capacitance as their size increases. Therefore, significant efforts have been dedicated to overcoming the fundamental limit set by the conservation of the étendue. One of the most promising and disruptive approaches is the conversion of high étendue into low etendue sources by the absorption of light and the re-emission of a collimated beam at a different wavelength. This approach is illustrated in Fig. 1.

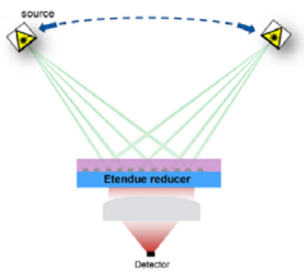

Fig. 1. Étendue reducer: Modulated light from a source is absorber omnidirectionally by a luminescent layer coupled to a metasurface. The emission of the layer is beamed towards a lens that focuses on a fast photodetector.

In this contribution, we show an approach to reduce the étendue of large area emitters by collective resonances in metasurfaces formed by arrays of plasmonic nanoantennas. Plasmonic nanoantennas are metallic nanoparticles supporting localized optical resonances that are associated with the coherent oscillation of free electrons. When arranged in a periodic 2D lattice, like the one shown in Fig.2 (a), the radiative coupling of the localized resonances can be enhanced by diffraction in the plane of the array. This enhanced radiative coupling leads to collective plasmonic resonances in the metasurface that can be used to modify the emission of luminescent material on top of the array, as illustrated schematically in Fig. 2 (b).[1]

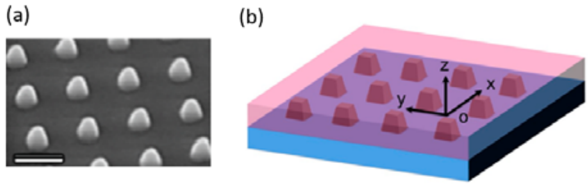

Fig. 2. (a) Scanning electron microscope image of a metasurface consisting of an array of aluminum nanoantennas. The scale bar represents 400 nm. (b) Schematic representation of a luminescent layer on top of a metasurface.

The working principle of the étendue reducer is illustrated in Fig. 1 and is the following: A modulated incident wave is absorbed omnidirectionally by the luminescent material. The excited material decays radiatively into the collective plasmonic resonances of the metasurface. This emission is coupled out in directions defined by the geometry of the array, giving rise to a beamed emission as illustrated in Figs. 3(a) and (b). The measurement in Fig. 3(a) corresponds to the emission of a layer of Lumogen red F305 dye in polystyrene, while the measurement in Fig. 3(b) is the emission of a similar layer of dye on top of the metasurface. The measurements of Fig. 3 are normalized to the emission of the dye on top of the metasurface in the direction normal to the surface. This emission is enhanced at elevation angles smaller than 8^{o}, illustrating a strong beaming and the concomitant reduction of the étendue when the luminescent layer is on top of the nanoparticle array.

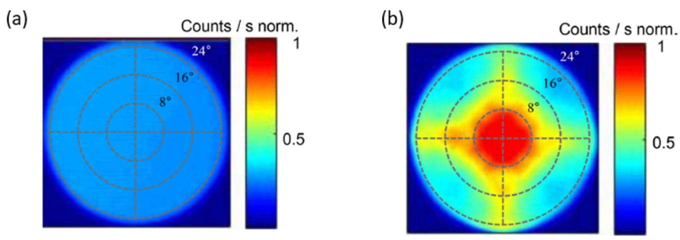

Fig. 3. (a) Angular emission of a thin layer (700 nm) of dye molecules in polystyrene. (b) Angular emission of a similar layer on top of a metasurface.

Band-limiting effects induced by the decay rate of the excited dyes can limit the performance to data rates lower than few Gbps. Therefore, high-quantum efficiency and fast recombination rate emitters are needed to achieve efficient étendue reduction for high bandwidth applications. This could be achieved by exploiting nanophotonic effects, such as Purcell enhancement.

References

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