Silicon nanopillar array for light emission enhancement in color-converting LED

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Introduction:

Plasmonic metallic nanostructures have been demonstrated an effective way to enhance the light emission efficiency in LEDs. Here, we propose a design of white LEDs that combining dielectric silicon nanopillar array in the color-converting layer. By investigating theoretically the guided mode caused by the nanopillar array-waveguide system, we demonstrate that the silicon nanopillar arrays enable larger near-field enhancement and more efficient photons emission property than the plasmonic counterparts [1]. These performances make the silicon nanopillar arrays have potential application in light converter for efficient white LEDs.

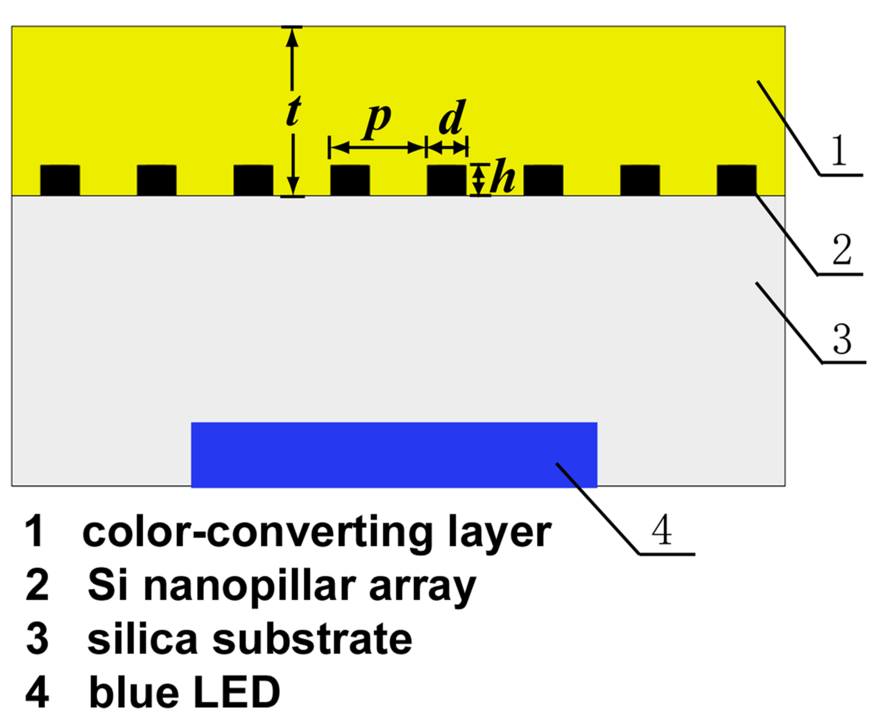

Fig.1 Schematic of the proposed structure.

Simulation method:

All calculations are performed in COMSOL Multiphysics® 5.1 with the wave optics module. Optical response of the nanoparticle array-waveguide system can be obtained by simulating a unit cell in the computational domain, with Floquet periodic boundary employed for four lateral boundaries and perfectly matched layers (PML) in the vertical (z) direction. To evaluate the extinction and near-field enhancement effects of the guided modes excited in polymer layer, the system is excited by a plane wave under normal incidence. For the investigation of the nanopillar array-mediated emission, the unit cell is driven by a classical electric dipole at the center of the color-converting layer.

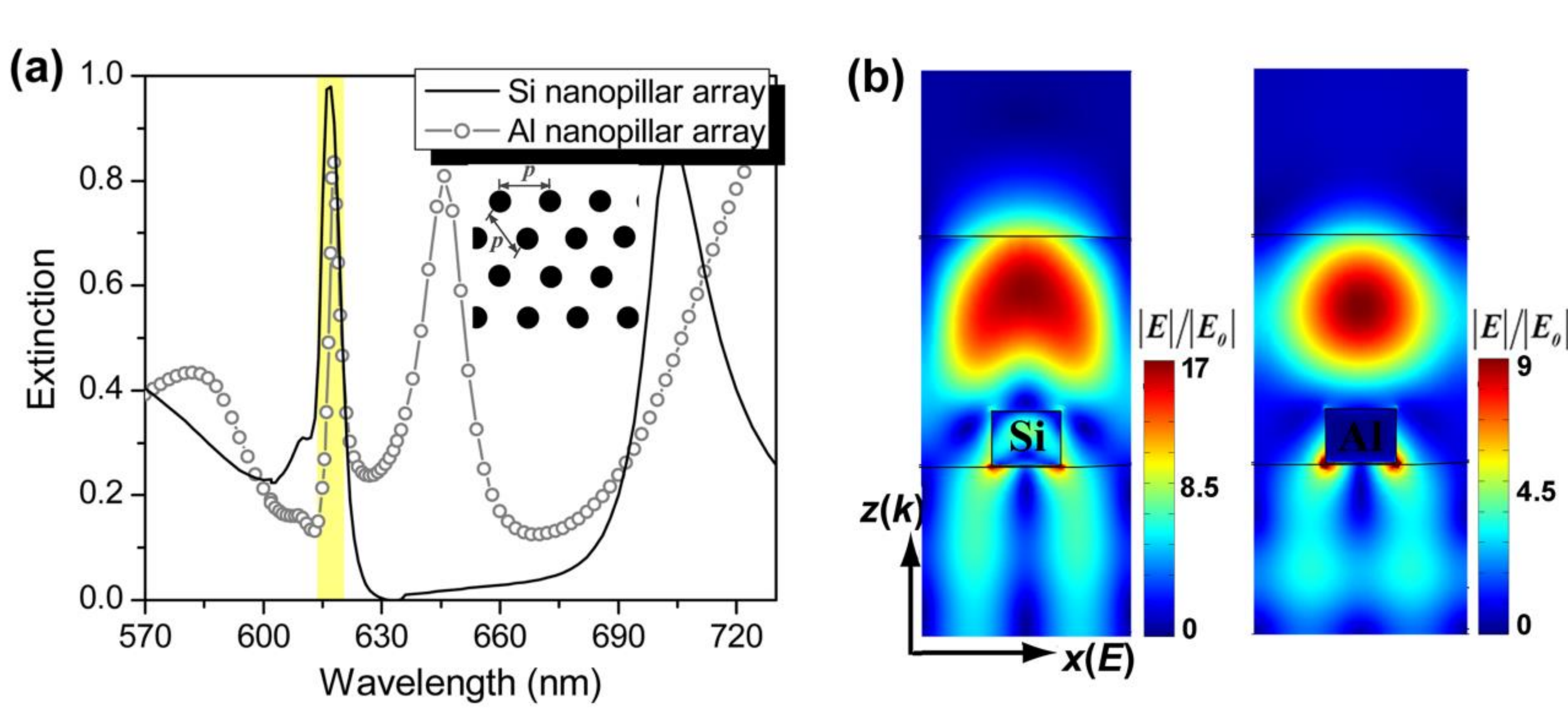

Fig.2 (a) Calculated extinction spectra of the hexagonal arrays of Si and Al nanopillars (b) Distribution of the E-field enhancement in a unit cell of the hexagonal array under the excitation of guided mode.

Conclusions:

Due to the low-loss directional scattering of single Si nanopillar [1], the array of Si nanopillars is demonstrated to enable more significant near-field enhancement and emission enhancement than its plasmonic counterparts (see Fig.2 and 3). The energy emitted to far field above the Si nanoparticle array is calculated to be almost 3 times the power in the absence of nanoparticle array, and 1.8 times the power in the presence of Al nanoparticle array (see Fig.4). This makes the light-converting layer deposited over Si nanoparticle array may be an efficient light converter [2,3]. We expect our research open a new path to design and optimize the solid-state lighting systems by introducing large-area silicon nanostructures. The results also provide insights into the design of all-dielectric metamaterials for gaining or lasing devices.

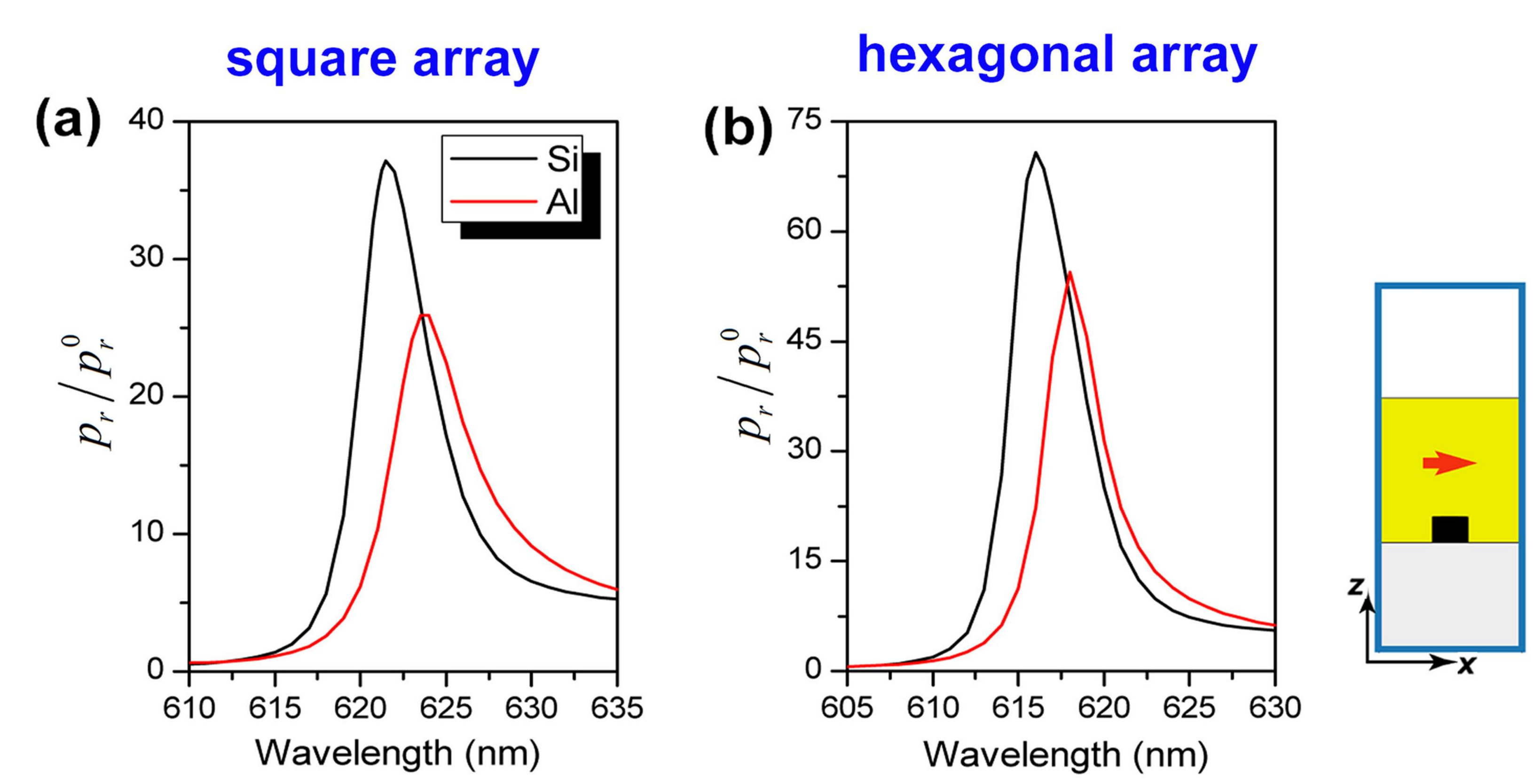

Fig.3 Emission enhancement spectra of the x-oriented electric dipole in the presence of square or hexagonal Si or Al nanopillar arrays. P_r and P^0_r are the power radiated by the emitter-waveguide system in the presence and absence of the nanoparticle array.

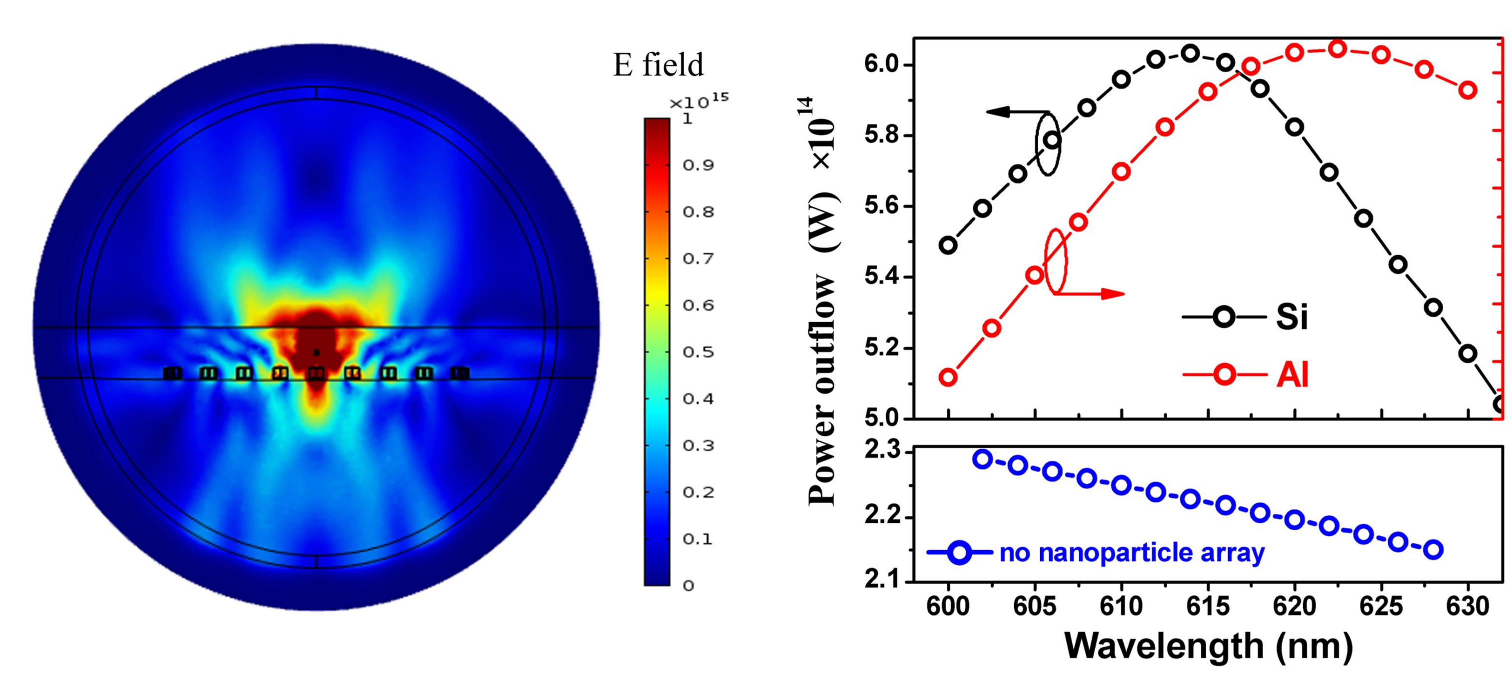

Fig.4 (a) E-field distribution of the Si nanoparticle array (9×9)-waveguide system as it is excited by an electric dipole source. (b) The power radiated into the upper space in the presence or absence of the nanoparticle array.

References:

1. B. Rolly et.al., Opt. Express 20, 20376-20386 (2012).
2. Pei Ding et.al., Opt. Express 23, 21477-21489 (2015).
3. Pei Ding et.al., in preparation.

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