SUPPLEMENTARY MATERIAL

Surface Lattice Resonance Enhanced Amplified and Directional Spontaneous Emission from Plasmonic Honeycomb Nanocone Array

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1. The optical propagation path of honeycomb lattice in reciprocal space

According to the orthogonal relationship, the primitive vectors $\mathbf{a_1}$ and $\mathbf{a_2}$ of real space (Fig. S1a) can be converted to the primitive vectors $\mathbf{b_1}$ and $\mathbf{b_2}$ of reciprocal space (Fig. S1b). The operated reciprocal lattice vectors can be expressed as $\mathbf{G_{ij}} = i\mathbf{b_1} + j\mathbf{b_2} = (i, j)$, where i and j are integers. The diffraction of light waves resulted from collective scattered wave propagating along the surface of plasmonic lattice. Based on the empty lattice approximation (ELA), the diffraction order (DO) vectors in the two-dimensional Bravais lattice is described as $\mathbf{k_{DO}} = \mathbf{k_{//}} + \mathbf{G_{ij}}$, where $\mathbf{k_{//}}$ is the incident wave vector component parallel to the lattice surface.

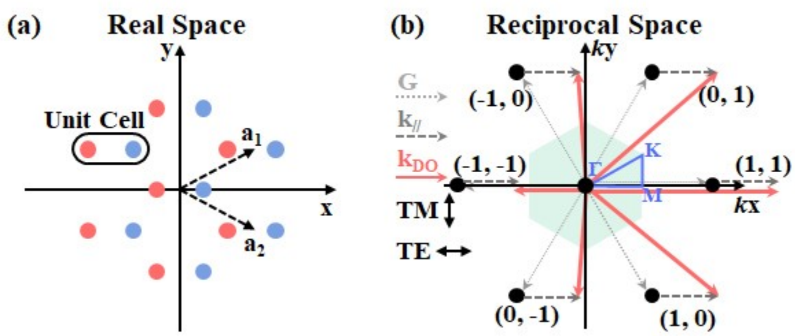

Fig. S1. (a) A honeycomb lattice in real space. (b) A hexagonal lattice in reciprocal space and the six lowest DOs.

2. Reflection spectra of the Al nanocone array under TM polarization

As shown in Fig. S2, the wavelength of resonance valley has a significant redshift with the increasing of incident angle. Only the spectrum of 25° (red line) accurately matches the central wavelength of R6G luminescence at 566 nm, which is marked by the red triangle. The full width at half maximum (FWHM) of the SLR mode is 26 nm (red dotted line) with an incident angle of 25° under TM polarization.

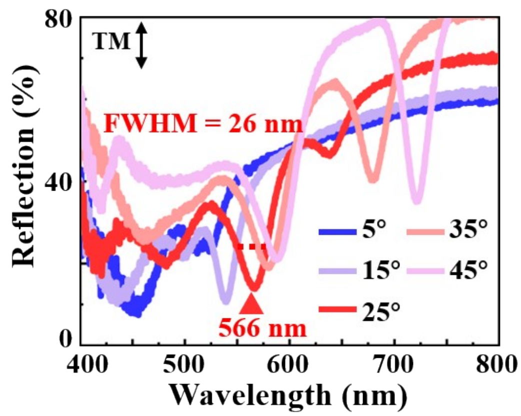

Fig. S2. Experimental reflection spectra of Al nanocone array under TM polarization at incident angles of 5°, 15°, 25°, 35°, 45°, respectively.

3. Optical characterization of Al nanocone array under TE polarization

The reflection dispersion of Al nanocone array under TE polarization is measured in Fig. S3a. The calculated degenerate DOs of (0, 1)/(1, 0) and (0, -1)/(-1, 0), two nondegenerate DOs of (1, 1) and (-1, -1) are represented by the dotted lines, respectively, which are partially fit with the measurement DOs in the reflection dispersion. The reflection spectra of different angles indicate that the resonance wavelength of SLR modes mismatch the emission wavelength of R6G at 566 nm under TE polarization (Fig. S3b). The FWHM of the SLR mode is 33 nm (purple dotted line) with an incident angle of 25° under TE polarization, which is wider than that of TM polarization.

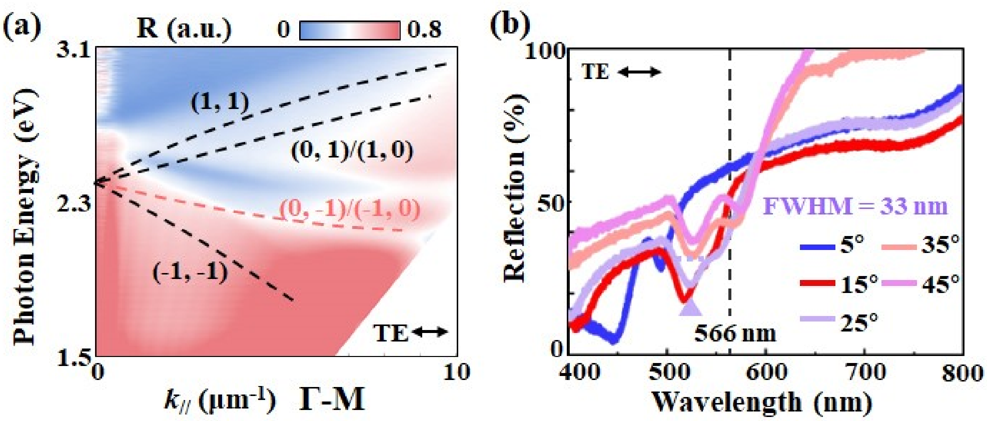

Fig. S3. (a) Experimental reflection dispersion of Al nanocone array under TE-polarization. The dashed lines represent the calculated DOs of (0, 1)/(1, 0), (0, -1)/(-1, 0), (1, 1) and (-1, -1). (b) Reflection spectra of Al nanocone array at incident angles of 5°, 15°, 25°, 35° and 45° under TE polarization. The emission wavelength of R6G at 566 nm is marked as black dashed line.

4. The near-field enhancement effect of Al nanocone array

The simulated electric field distribution of the honeycomb nanocone array is conducted by the Finite-difference time-domain (FDTD) simulation, as shown in Fig. S4a and S4b, in which the strong electric field confined at the tip of the nanocone due to the SLR mode. The intensity at the resonance wavelength exhibits a 3.2 times enhancement compared with that at off-resonance wavelength.

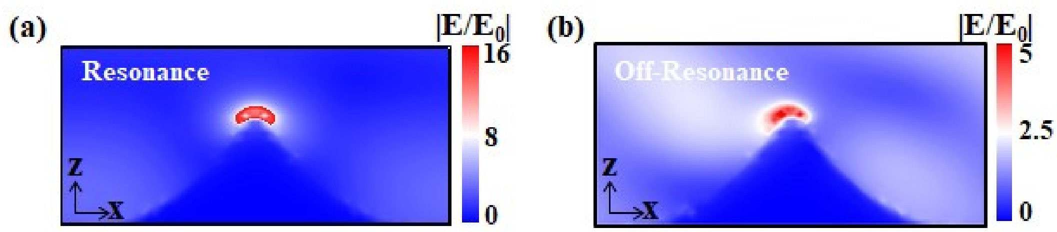

Fig. S4. Simulated electric field distribution of Al nanocone array on cross-sectional view at (a) resonance wavelength of 566 nm and (b) off-resonance wavelength of 600 nm using FDTD simulation.

5. Angle-resolved spectrum system

An angle-resolved spectrum system is applied to measure the amplified spontaneous emission (ASE) of R6G based on SLR mode supported by the Al nanocone array. As shown in the schematic optical path of Fig. S5, a laser of 532 nm serves as the pump source to excite R6G with a power density of 237 W/cm^2. The emission signal is transmitted to the spectrometer through reflection mirror, polaroid and optical fiber.

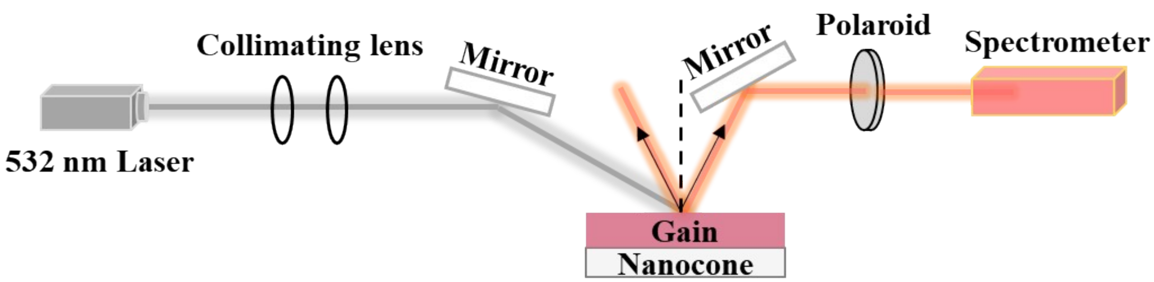

Fig. S5. Diagram of angular resolution optical path for the measurement of ASE.

6. The emission of R6G on glass slide

The directional modulation effect of the honeycomb nanocone array can be verified by comparing the angle-resolved spectra of R6G emission on glass slide. There is no angular characteristics of R6G emission on glass slide, as shown in Fig. S6. While a strong luminescence intensity of R6G is observed at emission angle of 25° on Al nanocone array.

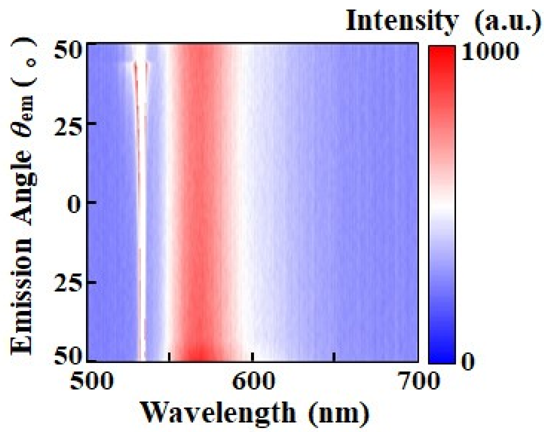

Fig. S6. Emission dispersion of R6G on glass slide with emission angle from -50° to 50° at incident angle of 60°.