Supplementary Materials

Optical Reflective Metasurfaces Based on Mirror-Coupled Slot-Antennas

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Supplementary 1. Simulation of the modified MCSA unit cell consisting of a slot-antenna on top of a SiO_2 spacer and a perfect electric conductor

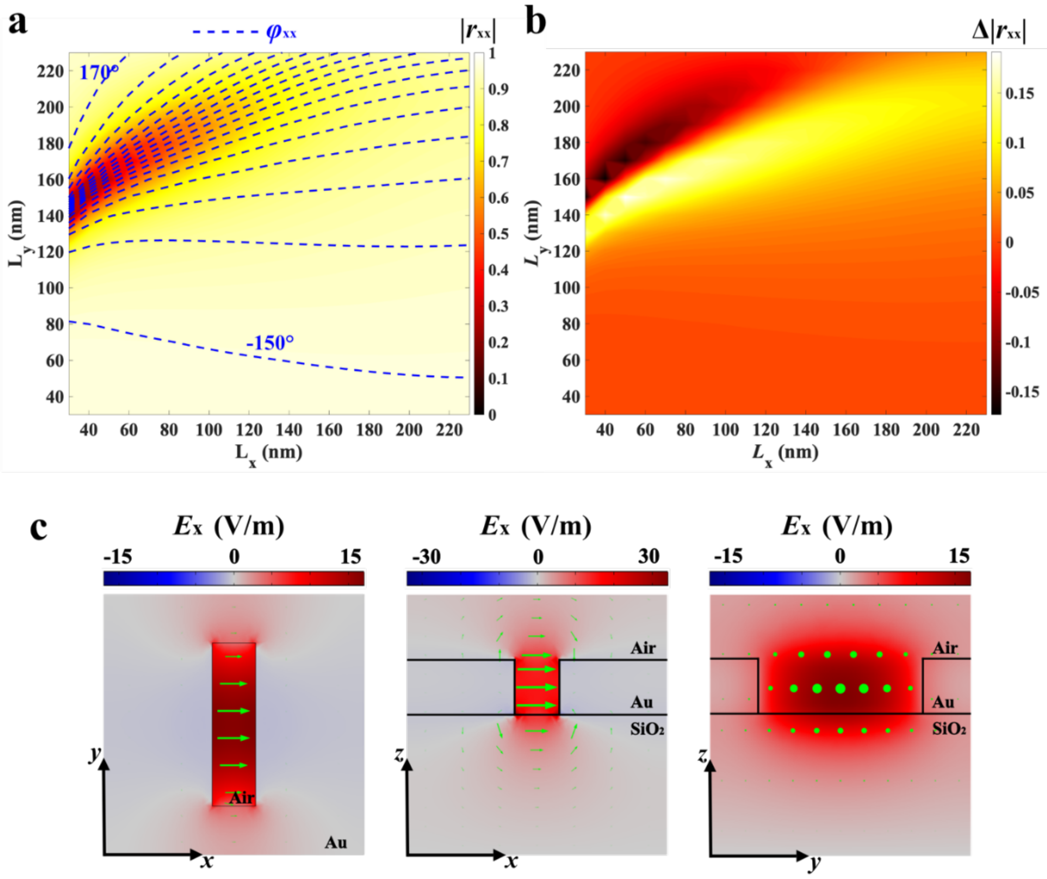

Figure S1. (a) Numerically calculated complex reflection coefficients as a function of the slot-antenna lateral dimensions at the design wavelength of λ = 785 nm upon TM-polarization. The meta-atom is composed of a slot-antenna and a perfect electric conductor separated by a SiO_2 spacer with a thickness of t_s = 130 nm. The amplitude $|r_{xx}|$ is visualized by the colormap, while the dashed blue lines are the contours of the reflection phase φ_{xx} ascending by a 20° phase step. (b) The calculated amplitude difference $\Delta|r_{xx}|$ in Figure 1(a) and Figure S1(a). (c) Cross-sectional electric field distributions in different cutting-planes for the slot-antenna at λ = 785 nm. The selected cutting-planes display the mode amplitude profiles within the center of the slot-antenna in the top Au layer. The color bars are chosen for illustrating the mode profiles of the E_x-component while arrows indicate the electric field vectors at a representative moment of time. The slot-antenna dimensions are L_x = 50 nm and L_y = 140 nm.

Supplementary 2. Dimensions and reflection coefficients of the selected 3 meta-atoms

The dimension of the three fabricated metaatoms for the beam-steering and beam splitting mirror coupled slot-nanoantenna (MCSA) metasurface with their corresponding phase and reflection amplitude are displayed in Table S1. For the beam-steering design the meta-atoms 1, 2 and 3 where selected. For the beam splitting design, the meta-atoms 2 and 3 were used.

Table S1. Dimensions and reflection coefficients of the 3 selected meta-atoms

No. of the meta-atom	L_x (nm)	L_y (nm)	φ_{xx} (deg)	$\lvert r_{xx}\rvert$
1	120	120	−130	0.89
2	120	180	−20	0.58
3	70	180	90	0.52

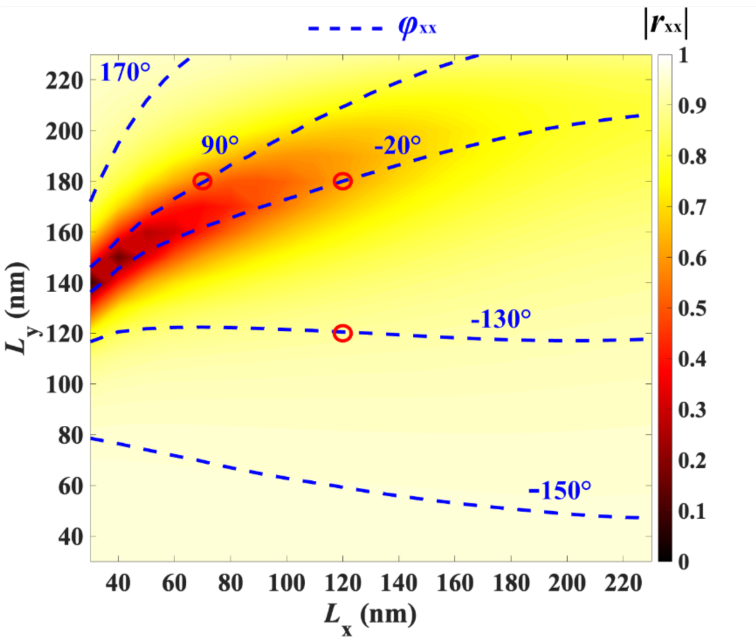

Figure S2. Numerically calculated complex reflection coefficients as a function of the slot-antenna lateral dimensions at the design wavelength of $\lambda = 785$ nm upon TM-polarization for a SiO_2 thickness of $t_s = 130$ nm and a gold substrate. the dashed blue lines are the contours of the reflection phase φ_{xx}. The red circles mark the dimensions of the selected meta-atoms.

Supplementary 3. Theoretical performance of the beam-steering MCSA metasurface consisting of meta-atoms with gradually varying sizes

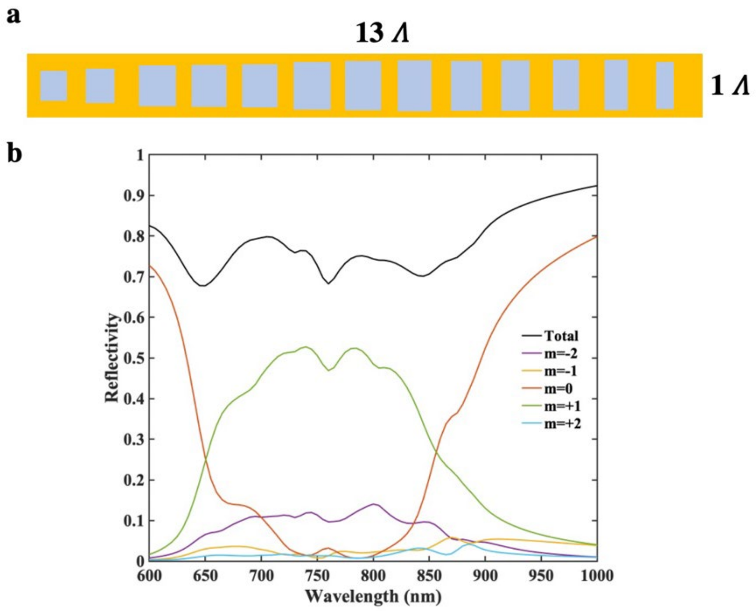

Figure S3. Theoretical performance of the beam-steering MCSA metasurface that reflects the normal incident TM-polarized light into the +1st diffraction order for a supercell consisting of 13 meta-atoms with gradually varying sizes. (a) Schematic of the simulated supercell. The dimensions of the meta-atoms from left to right are (1) L_x = 120 nm, L_y = 120 nm; (2) L_x =130 nm, L_y = 130 nm, 3) L_x = 170 nm, L_y = 145 nm, 4) L_x = 160 nm, L_y = 155 nm, 5) L_x = 160 nm, L_y = 170 nm, 6) L_x = 170 nm, L_y = 180 nm, 7) L_x = 165 nm, L_y = 185 nm, 8) L_x = 155 nm, L_y = 200 nm, 9) L_x = 140 nm, L_y = 200 nm, 10) L_x = 130 nm, L_y = 200 nm, 11) L_x = 120 nm, L_y = 200 nm, 12) L_x = 105 nm, L_y = 200 nm, 13) L_x = 80 nm, L_y = 190 nm. (b) Simulated diffraction efficiencies of different orders as a function of wavelength.

Supplementary 4. The optical setup for measurements

The custom-built experimental setup is shown in Figure S3. The near-infrared light from a fiber coupled wavelength-tunable Ti: Sapphire laser (Laser, Spectra-Physics, Model 3900S; wavelength range from 700 to 1000 nm) first passes through a half-wave plate (HWP, Thorlabs, AHWP05M-980) and an attenuator (Thorlabs, NE01B) to adjust the power of the output light. Then the output light passes through a linear polarizer (LP1, Thorlabs, LPN1R050-MP2) to generate a standard *x*-polarized beam. After that, the generated *x*-polarized beam passes through one silver mirror (Mirror, Thorlabs, PF10-03-P01) and 2 beam splitters (BS1 and BS2, Thorlabs, CM1-BS014) which could change the direction of the beam propagation and compensate for the actual phase retardance caused by a single beam splitter. Then the *x*-polarized beam is slightly focused on the sample with a spot size smaller than the sample area by a long working distance objective (Obj, Mitutoyo, M Plan Apo, 20×/0.42 NA). The reflected signal collected by the same objective passes through BS2, a tube lens (TL, Thorlabs, TTL200-S8, $f = 200$ mm), and an iris (Thorlabs, ID12Z/M) that located at the first direct image plane to select a specific area of interest in the sample for the measurement. The filtered first direct image plane is transformed by a relay lens (RL, Thorlabs, AC254-100-B-ML, f = 100 mm) to the corresponding Fourier image plane, whose intensity profile is captured by a COMS camera (Thorlabs, DCC1545M-GL). Note that the direct and Fourier images could be switched by a flip lens (FL, Thorlabs, AC254-100-B-ML, f = 100 mm). Another linear polarizer (LP2, Thorlabs, LPN1R050-MP2) is mounted between the camera and FL for polarization-resolved measurement. The efficiencies and polarization properties of the reflected light are measured on the Fourier plane, at which different diffraction orders are well separated in space.

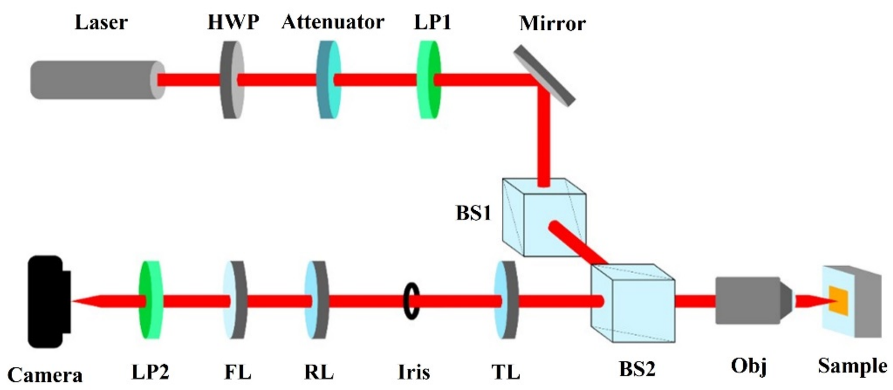

Figure S4 Schematics of the optical setup for characterizing the MSCA metasurfaces.