Silicon Perfect Absorber of Quadrupole Modes within the visible light range

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1. Introduction

Perfect absorbers based on metasurfaces are extensively studied owing to their engineered optical properties. Perfect absorbers can be used for thermal radiators [1] and imaging devices [2]. The absorptivity of an ultra-thin, freestanding film is limited to 50% in principle [3]. The limitation can be overcome by using all-dielectric perfect absorbers based on degenerate critical coupling (DCC) [4]. Dielectric Mie resonators can support electric dipole (ED), magnetic dipole (MD), electric quadrupole (EQ), and magnetic quadrupole (MQ) modes [5]. Huygens' metasurfaces have spectrally overlapped peaks of ED and MD modes [6]. By introducing moderate material losses to Huygens' metasurfaces, a perfect absorber can be realized [7]. In addition to ED and MD modes, we found that the concept of DCC applies to quadrupole modes.

In this paper, we design a silicon perfect absorber of quadrupole modes based on DCC in the visible light range. We illustrate that perfect absorption can be achieved with the spectrally overlapped peaks of EQ and MQ modes.

2. Results and discussions

Firstly, we study Mie resonators with the separated peaks of EQ and MQ modes. The schematic of designed elliptic-cylinder-shaped Mie resonators is shown in Figure 1a. The Mie resonators with major axis d_1, minor axis d_2, height h, and periodicity p are placed on a quartz substrate. Incident light polarizes along the major axis. In Figure 1b, we present the absorption spectral map of Mie resonators with h = 100 – 150 nm. At h = 150 nm, two peaks appear at 500 nm and 534 nm, respectively. According to field distribution, we can confirm that the two peaks are corresponding to EQ and MQ modes. The electric field distribution of EQ mode and magnetic field distribution of MQ mode are shown in Figure 1c and 1d. An EQ is made up of a pair of anti-parallel EDs while an MQ consists of a pair of anti-parallel MDs.

The concept of DCC requires that the peaks of EQ and MQ modes are spectrally overlapped. By reducing h, the peaks of EQ and MQ modes approach each other in Figure 1b. We indicate the tendency of EQ and MQ modes concerning h by a black dashed and a black dotted line, respectively. For the separated peaks of EQ and MQ modes, absorptivity is approximately 50%. With reduced h, absorptivity increases and reaches 99% at h = 108 nm. The perfect absorber based on EQ and MQ is realized.

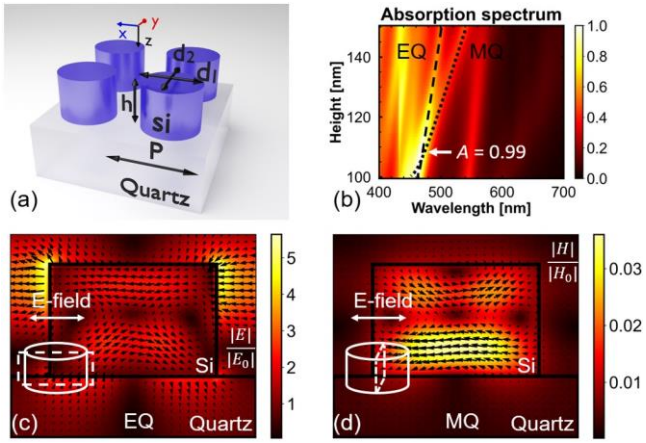

Figure 1. (a) Schematic of Mie resonators. (b) Absorption spectral map of Mie resonators with d_1 = 190 nm, d_2 = 176 nm, h = 100 – 150 nm, and p = 280 nm. (c) Electric field distribution of EQ and (d) magnetic field distribution of MQ at h = 150 nm.

3. Conclusions

We have designed a silicon perfect absorber of quadrupole modes based on the DCC. We present that the DCC applies to the higher-order modes of Mie resonators. The perfect absorber has the potential to be used for active metasurfaces mediated by the photothermal effect [8].

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