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Abstract – Silicon Mie resonators and metasurfaces were nanofabricated using electron beam lithography followed by wet chemical alkaline etching or reactive ion etching. The fabrication process was adapted for both amorphous and monocrystalline silicon in order to obtain efficient resonant light scattering by individual silicon particles. A large palette of colors was created by tuning the size, shape and aspect ratio of the particles.

Nanoparticles of high-refractive index dielectric materials like silicon are known to efficiently scatter incident electromagnetic waves. The extinction spectra show several well pronounced peaks corresponding to electric and magnetic dipole and quadrupole moments resonantly induced in the particles by the incident light. The spectral positions of these peaks are determined by the shape and the size of the individual particles as well as by coupling between the particles if they are situated close enough from each other. For the visible and near-infrared spectral regions, the typical sizes of individual resonant silicon particles are situated in the range from 70 to 250 nm [1,2].

The nanoparticles can be organized in order to form metasurfaces which allows to control collective effects and to optimize the interaction between the particles. For the metasurfaces constituted by the individual particles, the distances between them should be large enough in order to avoid possible near-field coupling. For example, recently we have fabricated the metasurfaces composed of silicon particles situated at distances larger than 1 μm providing vivid structural colors [2]. On the other hand, a metasurface composed of closely packed resonators has shown to be a very efficient antireflective coating in a large spectral range from the visible to the near infrared and it was fabricated by nanostructuring of monocrystalline silicon [3].

All the fabrication processes need to be carefully adapted to the active material and to the substrate in order to control the size and the shape of the individual nanoparticles and their organization in metasurfaces. We used amorphous and crystalline silicon to fabricate all-dielectric colored metasurfaces, absorbers and antireflective coatings. Amorphous silicon thin films were deposited onto transparent silica glass substrates. Then, the films were patterned by electron beam lithography followed by wet chemical etching in alkaline solutions [1] or by dry reactive ion etching [2]. Different materials such as gold and nickel were used to create hard masks adapted to the etching processes. We will also discuss an original maskless fabrication process using focused ion beam exposure.

We used wet chemical etching in two different types of alkaline solutions (based on potassium hydroxide and tetramethylammonium hydroxide) and we will discuss their influences on the shapes of the silicon resonators. The fabrication method was applied on both monocrystalline and amorphous silicon. In the case of crystalline silicon, the etching rates strongly depend on the orientation of the silicon crystalline planes, on the temperature and on the composition of the alkaline solution. The etching of monocrystalline silicon patterned with the same mask but in different alkaline solutions can give rise to the formation of nanofeatures with very different shapes [1]. In this case, very careful numerical simulations were needed to control the shape of the obtained features. Contrarily to the case of crystalline silicon, the etching rate of amorphous silicon is isotropic because of the isotropic atomic density. In that case, the final shape depends only on the shape of the mask. Dry reactive ion etching was also applied to both amorphous [2] and monocrystalline [3] silicon. This process allows obtaining a very good etching anisotropy and nearly vertical walls of the structures.

The shapes and the sizes of the obtained nanofeatures were controlled by scanning electron microscopy, and then the fabricated arrays of nanoparticles were characterized by optical spectroscopy in reflection mode with a dark-field microscope. The different scattering modes were identified as magnetic and electric dipole and quadrupole Mie resonances by comparing experimental and numerically simulated spectra. We also fabricated silicon monomers and dimers that were used to tailor the spontaneous emission of organic molecules.

In conclusion, we fabricated all-dielectric silicon metasurfaces by electron beam lithography followed by alkaline and reactive ion etching and we observed vivid colors provided by the resonant light scattering by individual silicon particles. The relative strength of the electric and magnetic resonances can be easily tuned with the aspect ratio of the particle. This allowed us to create a large palette of colors when considering the same particle height and simply tuning the aspect ratio of the particle by varying the diameter.

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