Fabrication method of tapered nanostructure via single-step deep reactive ion etching

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Abstract
Deep reactive-ion etching (DRIE) is a valuable fabrication method to fabricate deep holes or pillar with a highly anisotropic feature in sub-micrometer scale. Based on the single-step deep reactive ion etching(SDRIE), we found a suitable fabrication parameter for tapered nanopillar structure in crystalline silicon substrates. In our fabrication method, we can efficiently remove the "ripples" on a sidewall of etched structure because it doesn't require a time multiplexed step. With this fabrication method, we can achieve the low reflectivity silicon surface in the visible ranges.

Introduction
With increasing interests in metamaterial study, many researchers are trying to fabricate the matamaterials and experimentally verify the designed optical properties, such as negative refractive index or enhanced absorption.[1][2] The fabrication process of metamaterials, designed for visble or near-infrared wavelength range, requires state-of-the art fabrication technology because these metamaterials are composed of sub-wavelength(sub-micrometer) unit cells.

In this work, we are trying to fabricate the visible metamaterials for enhanced absorption without introducing any expensive or time-consuming fabrication technology, such as e-beam lithography and focused-ion beam(FIB). By using nanosphere lithography(NSL), inexpensive and efficient tool for sub-micrometer scale, we define a pattern of two-dimensional hexagonal array of polystyrene beads(diameter = 300nm, Thermoscientific. Inc.) as shown in Fig.1.

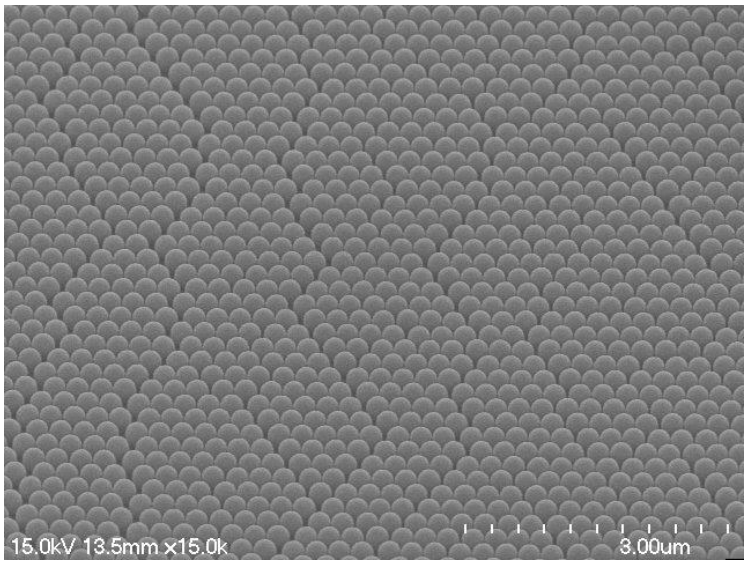

Figure 1.SEM image of two-dimensional array of polystyrene beads arrays on silicon substrate

After deposition of 2D PS mask, we etch the substrate via inductively coupled plasma (ICP) etching with SF_6 and C_4F_8. These two reactive gases are representative gases in conventional deep-reactive ion etching (DRIE or "Bosch" process). The DRIE has high etch rate and vertical sidewall. However, it suffer from the sidewall ripples from the time-multiplexed alternative steps for removal of substrate-SF_6 and passivation of sidewall-C_4F_8.[3]

A single-step deep reactive ion etching(SDRIE) is quite similar to DRIE, except for omitting the time-multiplexed step.[3] Withour the alternative steps, we can acquire the smooth sidewall profiles, which is essential for anti-reflective subwavelength structures.[4] As shown in Fig.2, we can make a smooth surface of tapered silicon nanostructure sidewall.

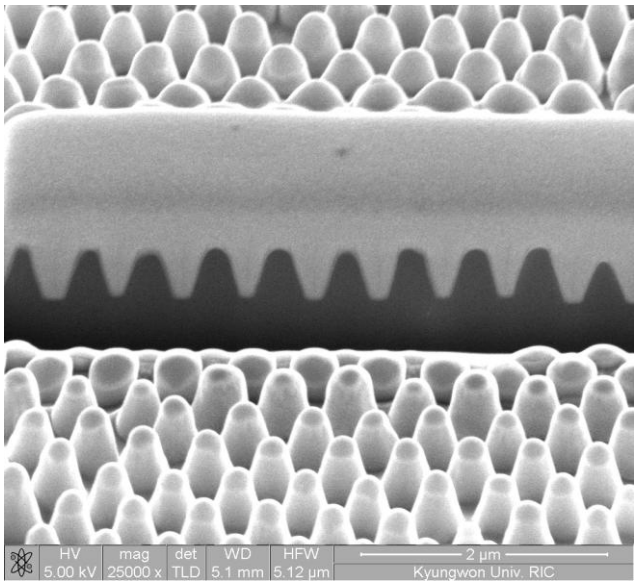

Figure 2. Sidewall profiles of silicon nanopillar: dual-beam FIB was used for the investigation.

This fabrication technique of metamaterials is very useful for fabricating a tapered nanostructure. The further details of our study are discussed at the conference *"Korea-Japan Metamaterials forum"*.

Acknowledgment

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