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Optical performance of Au hemispheric sub-microstructure on polystyrene quadrumer

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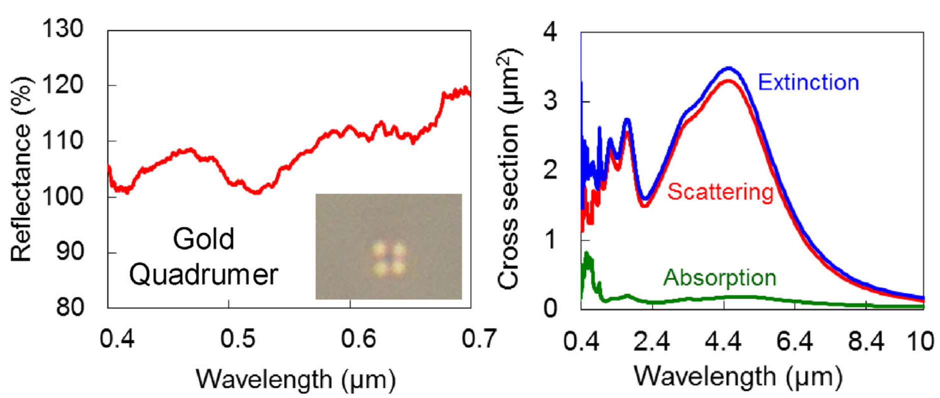
HIGHLIGHTS

- A sub-microsized gold-coated quadrumer was successfully obtained on a resin.
- The reflectance of quadrumer was sensitive to the thickness of the coated gold layer.
- Quadrumer showed higher order modes of surface plasmon resonance in visible range.
- The quadrupole mode of surface plasmon in quadrumer theoretically appears at 3.4 μm.

GRAPHICAL ABSTRACT



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ABSTRACT

The microfabrication process of a hemispheric gold quadrumer structure and its optical performance was investigated. A quadrumer structure consisting of polystyrene spheres coated with gold thin hemispheric shell was prepared. The difference in the interfacial free energies in the gold/polystyrene and gold/silicon interfaces enabled the gold-coated quadrumer structure to be peeled from the silicon substrate without peeling the gold layer on the silicon substrate. Microspectrophotometry revealed that the thicker gold layer of the quadrumer could provide a reflectance increase, and the behaviours in the measured reflectance were in good agreement with the calculated optical spectra in the visible range. Theoretical calculation predicted that the optical quadrupole mode of the localized surface plasmons could be excited at 3.40 μm of light in the presence of a *p*-polarized oblique plain wave from the topside of the quadrumer structure.

1. Introduction

Metal nanostructures play a critical role in a variety of academic and industry fields [1,2]. Recent reports demonstrated the

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efficiency improvements in traditional research fields, such as photovoltaics [3–5], thermoelectrics [6] and photocatalyst [6,7], could be achieved by combining metal nanoparticles with semiconductive metal oxides. Other reports emphasized the indispensable role of the metal nanostructure in so-called metamaterials that show negative index refraction and are, therefore, expected to create new optical applications, such as light cloaking or super lens [8–10]. Because the size and structure of the metal nanostructures are significant factors that define their optical performances, many metal structure types have been widely investigated with both theoretical calculations and real measurements [11–15].

A research hurdle to overcome is the technique for fabricating a real micro- or nano-size metal structure. There are two typical approaches in micro/nano-fabrication, top-down [16,17] and bottom-up [16,18,19]. Top-down and bottom-up generally have complementary advantages and disadvantages with respect to the shape control, fabrication precision, energy consumption, and operation duration. Several reports demonstrated the value of integrating top-down and bottom-up approaches, enabling us to leverage the advantages and minimize the disadvantages of the various methods [14,20]. Our group demonstrated the effectiveness of integrating top-down and bottom-up approaches in the micro-size quadrumer fabrication process, as previously reported [21]. The quadrumer structure is a configuration that consists of four spherical particles that are symmetrically arranged at the corners of the square. This structure is expected to be an attractive structure because of its possibility for showing a negative index response against visible light [15].

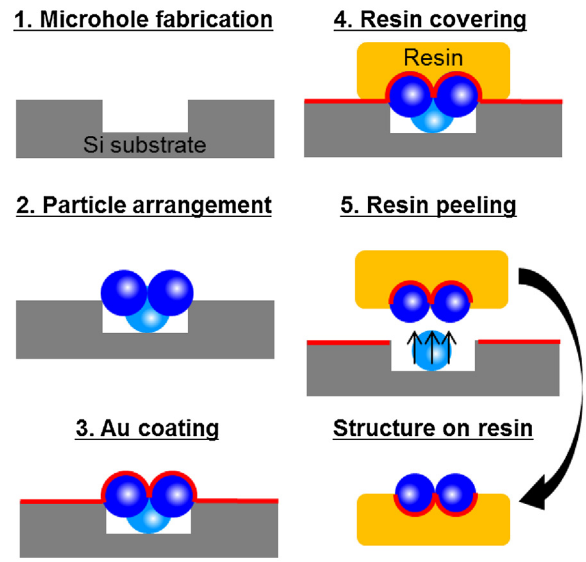

Fig. 1. Schematic illustrations of the microfabrication process for a quadrumer structure.

In this study, we investigate the optical properties of the quadrumer structure that consists of a hemispheric thin gold shell as a continuation of our previous work [21]. Although the electric and magnetic properties of the quadrumer structure with

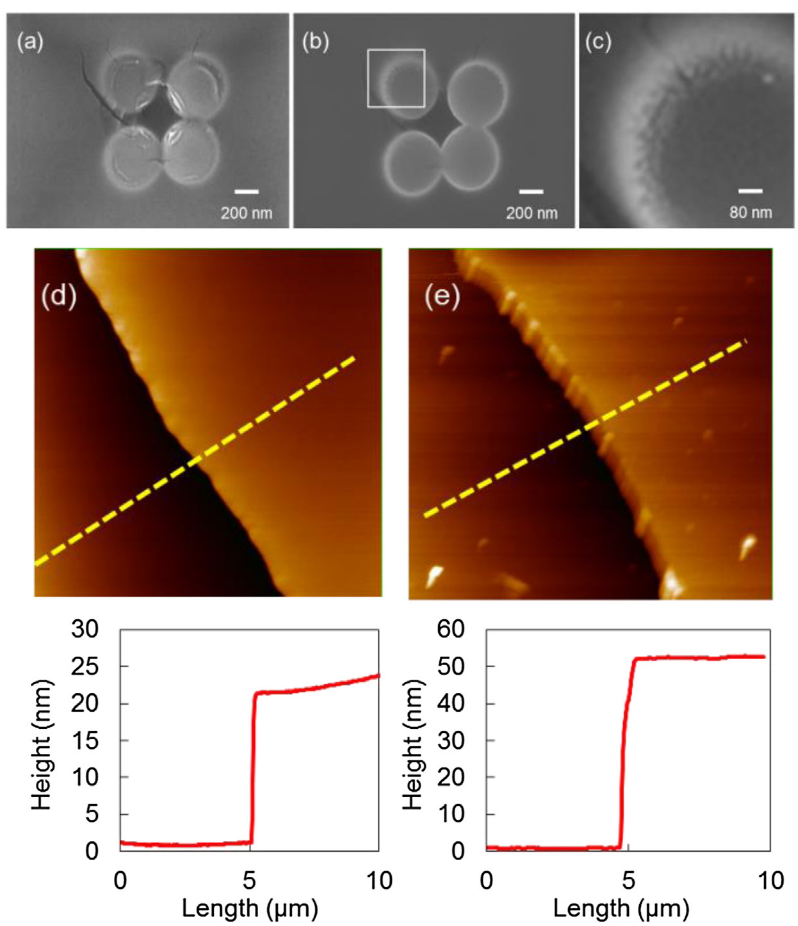

Fig. 2. (a–c) SEM images of the gold-coated quadrumer structure on a substrate resin; (a) secondary electron image; (b) reflection electron image; and (c) zoomed image in the square region in (b). (d, e) AFM images of the edge of a thin gold layer with (d) 20-nm and (e) 50-nm thickness after peeling resin. The height distributions along the dot lines are inserted below the AFM images.