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Short communication

Light absorption with branched gold cauliflower-like nanostructure arrays

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In the present study, we have investigated the growth of branched gold (Au) cauliflower-shaped nanoparticles on Cicada's wing nanonipple arrays. The gas aggregation dc magnetron sputtering nanocluster source without size filtration was employed for fabrication of the samples. It was observed that the operating conditions of dc magnetron sputtering, such as gas pressure in the aggregation chamber and discharge power, control the deposition of charged clusters. By changing the operational conditions, a nanocauliflower-like (NCF) structure grew on the nanonipples. This Au nanostructure with a cauliflower-shaped surface feature was monitored using scanning electron microscopy (SEM) and atomic force microscopy (AFM). The optical properties of these branched gold nanostructure arrays were also studied. Reduction of light reflection and the consequent light trapping suggest use of this branched structure for achieving broadband light absorption in Plasmonic solar cells as a result of plasmonic effects.

Nanostructured (NS) noble metal materials of a particular morphology have attracted broad attention. As one of the most important metal nanomaterials, branched metal NS materials have been widely applied in optical, electrical, catalytical and biomedical fields [1–5]. In this regard, branched gold (Au) NS materials are of particular interest that arises from their unique surface-sensitive properties, large number of multiple surface edges and large surface–to–volume ratio [1,3,5,6]. It would be also feasible to tune the fascinating properties of Au branched structures such as their optical and electrical properties by size and shape modifications [7,8]. For instance, gold nanoflower-like structures exhibit intensely surface-enhanced Raman spectroscopy (SERS) signals in comparison with simply bumped Au nanostructures [8].

Many efforts have been devoted to develop new methods for the fabrication of gold nanostructures with defined size and morphology [8–12]. There are a few ‘wet-chemical’ methods now available for synthesis of branched Au NS that are generally based on electrodeposition of gold particles [9]. Cauliflower-shaped Au nanoparticles (NPs) as a branched structure have been fabricated by electrochemical methods in an aqueous medium [9,11]. In these methods, NPs could be collected as a colloidal suspension at the end of the process [10]. Also, the electrodeposition of micro/nano Au structures on patterned and molecular modified solid substrates has been reported [11–13]. A two-step route has been carried out for construction of Au cauliflower-like hierarchical micro/nano structures randomly arranged on a solid substrate using a combination of initially random sequential adsorption (RSA) of Au NPs and, subsequently, the electrochemical deposition implemented [12]. Also, the effects of substrate surface morphologies on the directed electrodeposition of gold complex NS with cauliflower-shaped surface features have been reported [13]. A ‘dry’ technique has been employed using a gas aggregation magnetron sputtering nanocluster source in a radio frequency (RF) mode to fabricate semiconductor branched NPs [14]. The advantage of this production method is simplicity and processing speed [14,15]. This high-production volume scheme is similar to the laser vaporization technique [16]. Fabrication of silicon cauliflower-shaped NPs on glass substrates using the gas aggregation magnetron sputtering nanocluster source has been reported earlier [15].

The Cicada wing with ordered patterns has been used as a

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sample substrate since it is known as an antireflective and replicable substrate which is easily separable from the deposited layer [17,18]. In this study, we have explored a (practical) method to produce Au nano-cauliflower arrays on Cicada's wing patterns using a gas aggregation nanocluster source through dc magnetron sputtering.

The cicada wing samples (Cryptympana atrata Fabricius C_0) which had quasi-ordered nano-nipple arrays on their surface were selected (Fig. 1). The sample substrates were cut in a $10 \times 7\ mm^2$ surface area and cleaned before use.

Deposition of gold NPs was carried out based on the gas aggregation procedure using dc magnetron sputtering technique by a commercially available system (DSR1, Nanostructured coating Co.). The deposition process took place in a vacuum chamber, and the substrates were fixed at 90 mm from a dc planar magnetron (80 mm in diameter), perpendicular to the cluster source axis. Au nanoclusters produced by gold target in the magnetron sputtering source were dealt with at room temperature. The base pressure in the deposition chamber was $\approx 7 \times 10^{-6}$ mbar. During magnetron sputtering with pure Ar gas, the pressure was applied from 13×10^{-2} to 17×10^{-2} mbar. The discharge power during sputtering was in the range of 120–175 W. The Ar flow rate was regulated by means of a mass flow controller (MKS Instruments) between 40 and 55 sccm (standard cubic centimeter/minute).

Three cicada wing/Au structures with three different operational conditions (i.e. C_1, C_2, and C_3) were fabricated. In the aggregation chamber, different conditions of Ar gas pressure and discharge power were applied while other parameters such as distance from magnetron source and gas temperature were kept unchanged. A 3D gold branched nanocauliflower-like structure began to turn out. The surface morphology of the Au NS samples was monitored using scanning electron microscope (SEM) images. The images were recorded using the TESCAN SEM system. The SEM images of the reference sample C_0 (cicada wing) showing the nanonipple arrays and Au NS obtained in different operational conditions (C_1, C_2, C_3) are shown in Fig. 1. Also, a tilted view of the cicada wing template is given in Fig. 1(C).

Different operational conditions of the gas aggregation chamber and the discharge power for fabrication of samples C_1, C_2, and C_3 are given in Table 1. The gold branched nanoparticle arrays forming over a large area can be seen in samples C_1, C_2, C_3. The Au NCFs on sample C_3 have surface edges and a branched surface that is arranged on the substrate largely with an upward head direction.

In the case of sample C_1, no branched structure can be seen on nanonipples, the surface feature is quite smooth in sample C_2, and branched NPs are observed. However, for the conditions in sample C_3, during the Au NPs deposition process, Au NPs were aggregated on the cicada wing substrate in such a way that NCF was formed.

Table 1
Different operational conditions of the gas aggregation chamber and the discharge power for fabrication of samples C_1, C_2, and C_3.

	Sample C_1	Sample C_2	Sample C_3
Ar Gas pressure (mbar)	13×10^{-2}	15×10^{-2}	17×10^{-2}
Discharge Power (W)	120	140	175

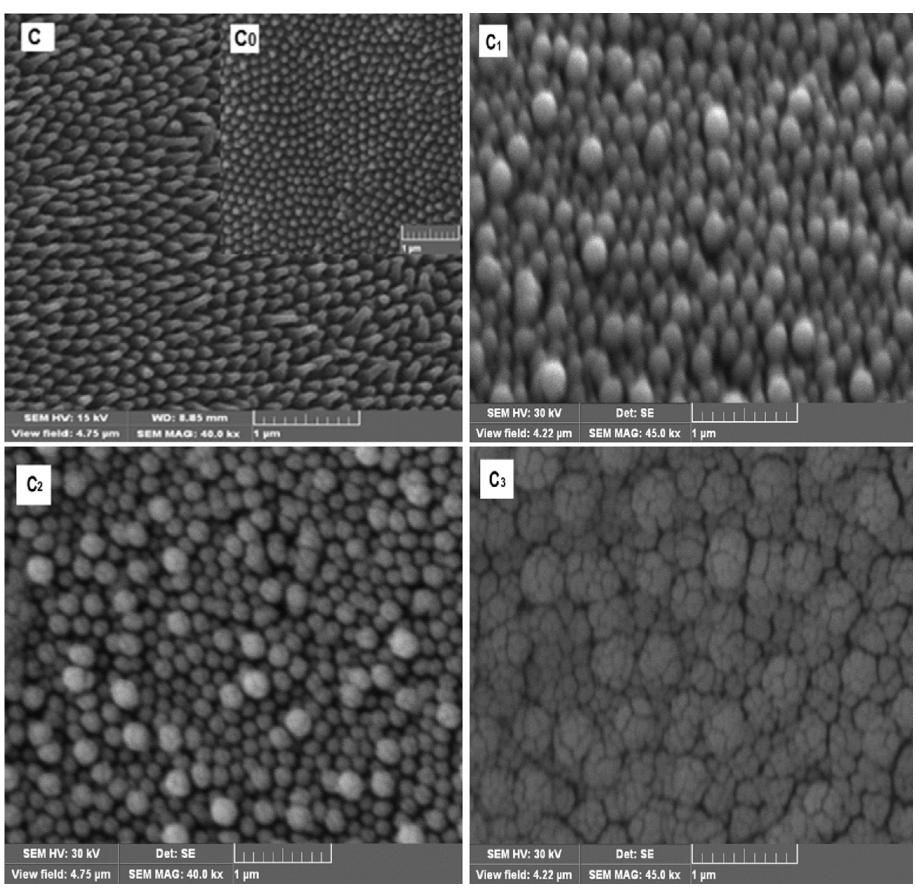

Fig. 1. Low-magnification top-view and tilted-view (C), SEM image of cicada wing substrate (C_0) gold nanoparticles particles grown onto the cicada wing substrate with different operational conditions of the magnetron sputtering. Discharge power of 120 W and Ar gas pressure of 13×10^{-2} mbar; (C_1), the discharge power of 140 W and Ar gas pressure of 15×10^{-2} mbar (C_2), gold cauliflower nanostructure grown onto the cicada wing substrate with the discharge power of 175 W and Ar gas pressure of 17×10^{-2} mbar (C_3) (Top view).