Flexible Nanoporous Anodic Aluminum Oxide(np-AAO) Template Coated with Self-Assembled Au Nanocrown Array for Photonic Switching

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ABSTRACT

This study reports a nanoporous anodic aluminum oxide (named np-AAO) template coated with Au nanocrown array on PET substrate for photonic switching application. In this flexible photonic device, the Au nanocrown array for photonic switching are self-assembled on flexible np-AAO/PET template at its one end using batch processes. The advantages of such nano-structure photonic device are as follows, **(1)** the photoconductivity of photonic device is increased by nanostructure; and **(2)** the photoelectron transport induced by localized surface plasmon resonance can be increased by the Au nanocrown array/np-AAO flexible template. **(3)** The np-AAO template with higher flexibility and compatibility are promising nanotemplate for flexible application. In applications, flexible photonic device consisted of Au nanocrown array on np-AAO flexible template is implemented. Measurements demonstrate the sensitivity and photonic instant response of the nanostructure photonic device is significantly enhanced.

INTRODUCTION

Flexible photonic devices can find extensively applications in optoelectronics. The operation techniques of flexible photonic devices to date can be identified as photoconductivity of nanocomposites materials approaches[1-2]. Many flexible photonic devices achieved by multi-nanocomposite [3], composite nanomaterials [3-4], multi-quantum well structure [5] have been reported. Thus, the nanocomposites-based flexible photo device shows wider wavelength detection range, and provides more applications for optoelectronics circuit and telecommunication. The existing flexible photonic device is realized using the nanocomposites solution, but complicated processes are required for these approaches.

The np-AAO template with uniform/dense nanoscale pores is a promising material for nanotechnology. The characteristics of transparent, photo-stability and mechanical-stability of np-AAO template provide additional advantages for optoelectronics devices [6-7]. In addition, the np-AAO nanostructure material has also demonstrated its capability for flexible electronics [7-8]. In these applications, the np-AAO film acting as a template to enable the formation of multifunctional nanostructure on flexible substrates.

This study further establishes np-AAO flexible template processes to enable the precision self-assembly patterning and batch fabrication of flexible photonic device and sensor. Thus, the flexible and vertically aligned np-AAO template is embedded onto the PET film using the batch fabricated micromachining process to form the presented device. To demonstrate the feasibility of this device, the Au nanocrown has been grown on an np-AAO flexible template via evaporation, and then self-assembly surface patterns of Au nanocrown array onto an np-AAO flexible template. The photonic switching responses are successfully measured using the np-AAO flexible photonic devices.

DESIGN AND FABRICATION

Fig.1 illustrates the flexible photonic devices consisting of Au nanocrown array and np-AAO template/PET substrates. The np-AAO template is grown on the surface of PET flexible substrate, and the Au nanocrown array is self-assembled onto np-AAO flexible template. As indicated in the cross section, the Au nanocrown array is patterned onto an np-AAO flexible template to realize the flexible photonic device. The pattern and integration of the presented flexible photo device can be easily implemented using batch micromachining process. This device employs the Au nanocrown array as the photonic transmitting area. In addition, Au nanocrown array with np-AAO flexible template has a higher conductance when begin illuminated by a different wavelength of laser beam. As the laser beam is focused on the np-AAO flexible photonic devices, the photonic is conductivity by Au nanocrown array with np-AAO flexible template, and then the localized surface plasmon resonance (SPR) is generated. The photoelectrons transport toward the positive and negative electrodes after applying the laser beam, and the photocurrent response is thus generated.

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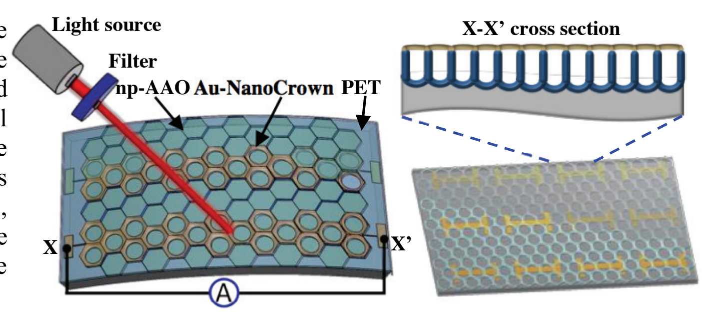

Figure 1 Schematic of presented flexible photonic device

This study has established the fabrication processes shown in Fig.2 to implement the proposed flexible photonic devices with Au nanocrown array on np-AAO flexible template. First, PET substrates were cleaned by ultrasonication in acetone, and then the Al film was evaporated by E-gun, as shown in Fig. 2a. As illustrated in Fig. 2b, after evaporating Al film onto the PET flexible substrates, the np-AAO template with uniform and high density nanoporous was grown via anodization process in 0.3M oxalic acid (at 40V and 7°C). After that, PET substrates with np-AAO template were bonded together as np-AAO flexible template; the np-AAO nanostructure defined the photonic functional area of Au nanocrown array, and then the Au nanocrown array was then patterned into the photonic functional areas by E-gun, as in Fig.2c. Thus, the np-AAO flexible template not only employed to assemble the Au nanocrown array but also acted as the photonic functional areas to conductivity of photoelectrons. In Fig.2c, the flexible photonic device with small and arbitrary patterns was batch fabricated.

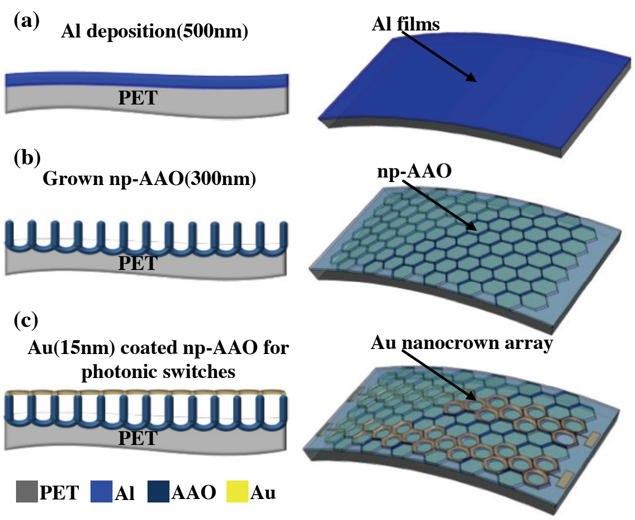

Figure 2: Fabrication process steps

RESULT AND DISCUSSION

Fig.3 shows typical fabrication results. The photo in Fig. 3a demonstrates the bending of PET flexible substrate with np-AAO template has good transparency. The field emission scanning electron microscope (FESEM) was used to characterize the surface morphology of the Au nanocrown array with np-AAO flexible template. The FESEM micrograph in Fig. 3b shows the typical morphology of np-AAO template. The Au nanocrown array was stacking with np-AAO flexible template, as in Fig. 3c. The side view micrograph in Fig. 3d shows the stacking of Au nanocrown array, np-AAO flexible template. The photo in Fig. 3e shows the photonic functional are of flexible photonic device after patterned the Au nanocrown array onto the np-AAO flexible template. Typical flexible photonic device and the flexibility of presented device is demonstrated in Fig. 3f. In this case, the flexible photonic device is 120µm thick. The transparent and opaque regions represent the np-AAO flexible template and Au nanocrown array, respectively. The in-plane dimensions of each flexible photonic device is 2cm×2cm.

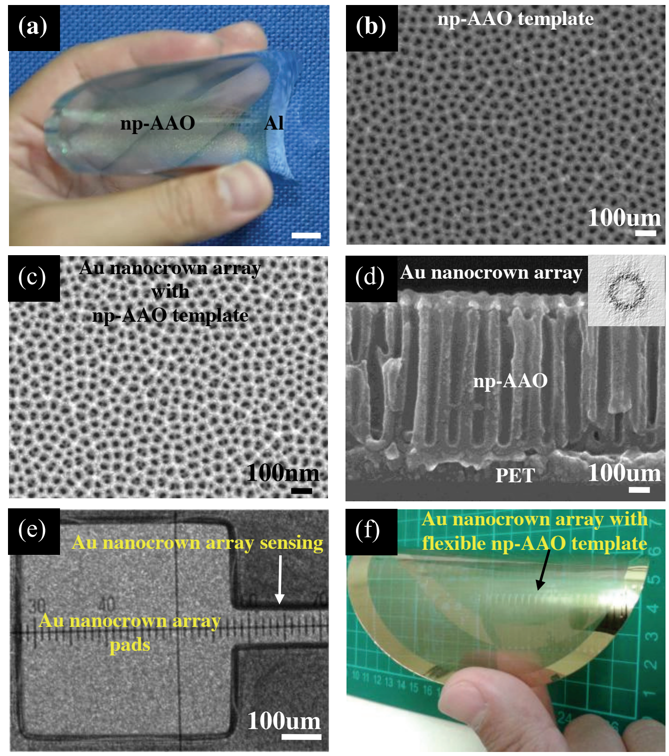

Figure 3: Typical fabrication results, (a) bending of np-AAO template on PET substrate, (b) np-AAO template, (c-d) FESEM image of top view and side view of Au nanocrown array with np-AAO flexible template, (e) photo of microstructure of flexible photonicdevice and (f) image of flexible photonic device.

Figure 4 shows the measured extinction profile of np-AAO flexible template with Au nanocrown array by UV/VIS/NIR spectrometer (wavelength ranging from 350nm to 800nm). The transmittance of a 4-in np-AAO flexible template was also recorded as a reference. Over the wave length of 350-800nm, the np-AAO flexible template with Au nanocrown array has extinction band with maximum located at 450nm, while that for np-AAO flexible template is non-extinction. This extinction profile of np-AAO flexible template with Au nanocrown array presents the special absorption spectral ranges, which is good for photonic switching. In comparison, the extinction profile of np-AAO flexible template with Au nanocrown array was extinct at around 450nm, 560nm, and 633nm because the Au nanocrown array with np-AAO flexible template has different refractive index for different light beam. Moreover, the measurements in Fig. 4 also depict the extinction profile is enhanced after staking a different dimension of Au nanocrown array with np-AAO flexible template.

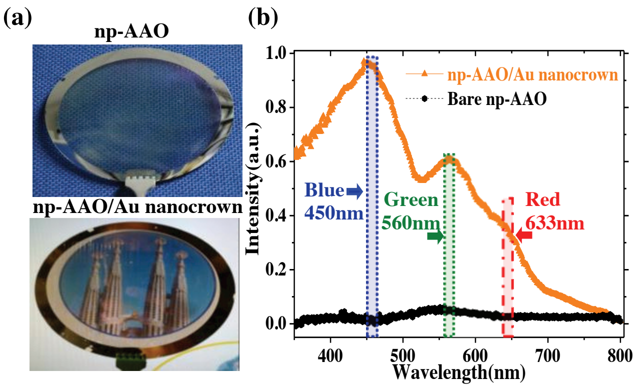

Figure 4: UV/VIS/NIR extinction profile of flexible photonic device with Au nanocrown array/np-AAO flexible template

The system shown in Fig. 5a was established to examine the photonic response of the fabricated flexible photonic device with np-AAO flexible template and Au nanocrown array, as proposed by this work. The flexible photonic device was placed between the filter and picoam meter, with a laser as a light source, and a picoam meter to record the photocurrent of the flexible photonic device. This system also examines the photoelectronics properties and the photonic switching of the flexible photonic device with different laser beam driving voltages and power. Fig. 5b shows the photocurrent of the flexible photonic device with different driving power of laser beam. The results also indicate that the bias voltage was around 20V, and the flexible photonic device provides a maximum photoconductivity state at wavelength of 450nm. As the driving voltage increased, in Fig. 5c, the flexible photonic device reaches its maximum photoconductivity state still with a wavelength of 450nm. The results indicate the photonic switching strongly dependent on the Au nanocrown array with np-AAO flexible template, and thus good photocurrent as well as photonic switching can controlled by applying voltage or power of light source.

Fig.6a shows the measurement setup to characterize the photonic switching performance of the fabricated flexible photonic device. A different wavelength of laser beam is incident on the sample, and the photocurrent response of the flexible photonic device is recorded by the picoam meter. The flexible photonic device is mounted on a round post. Fig.6b records the photonic switching of flexible photonic device under the B, G, and R beam illumination, respectively. The flexible photonic device, showing the maximum photocurrent of 6, 12.8, and 32pA with on-off cycle of 60s of three laser light beam in Fig. 6b The result indicates the flexible photonic devices has a higher sensitivity and fast photonic instant response.

Figure7 shows the test on the flexible photonic array device. Measurement result shows the photocurrents recorded by two different flexible photonic pixels (FPS1, FPS2), as the light beam switched from FPS1 to FPS2. Thus, the feasibility of the flexible CNTs photosensor array has also been demonstrated.

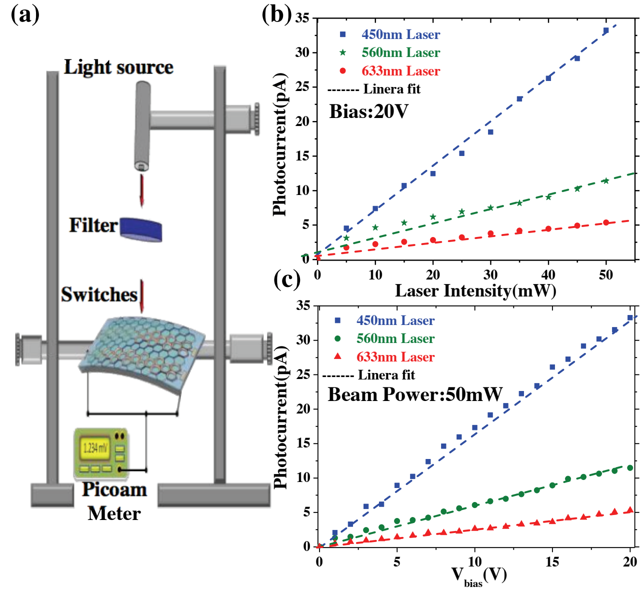

Figure 5: (a) flexible photonic switches characterization test setup, and (b) photocurrent response as varied beam power density with 20V bias-voltage, (c) photocurrent response as varied bias-voltage with 50mW beam.

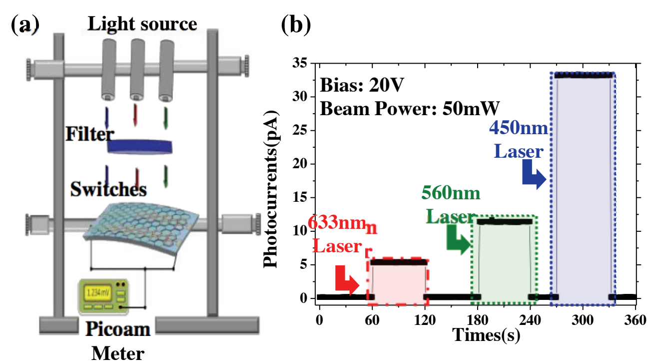

Figure 6: Test setup and results to characterize the R, G, and B beam focused on flexible photonic switches.

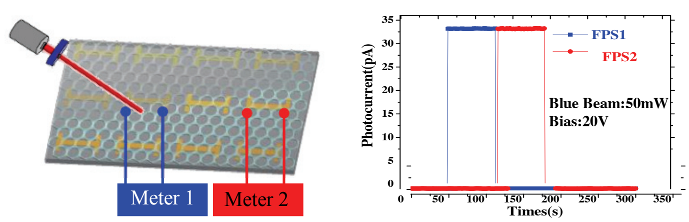

Figure 7: Photocurrent responses as beam focused on two different pixels (FPS1, FPS2) of flexible photonic switches.

CONCLUSION

This study has successfully demonstrated the flexible photonic device to switching by the laser light source. The Au nanocrown array with np-AAO flexible template can detect wide light wavelength for optoelectronics circuit and telecommunication application, etc, and np-AAO flexible template offers flexible substrate. Fabrication was based on a three-step process including, (1) np-AAO template growth, (2) np-AAO flexible template binding, and (3) Au nanocrown array pattern. In short, such flexible photonic device can be implemented using the batch fabricated processes. The photonic responses of the presented flexible photonic device are characterized as a function of ambient pressure and light wavelength. The measurements indicate that the presented device is operated in light wavelength of 450, 560, and 633nm, and generally produces photocurrent of 6~32pA under 20V, 50mW of incident light. Thus, the Au nanocrown array with np-AAO flexible template is controllable, optical and mechanical-stable layer; and that is promising multifunctional nanostructure for optoelectronics applications.

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