# Acceleration of Electrochromic Response using Metamaterials

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**ABSTRACT**

*Au nanoparticles were immobilized on the ITO electrodes by electro-deposition with a pulse voltage; the optical properties of the resulting electrode were studied. It was found that the transmittance of the resulting electrode containing the plasmon scattering could be controlled without the change in the wavelength of the absorption maximum. When a poly(3,4-ethylenedioxithiophene) (PEDOT) film was immobilized on the surface of the obtained electrode, the electrochromic response of the PEDOT film was remarkably accelerated: the total process including the colouring and bleaching was compressed from 0.402 s to 0.347 s, in particular, the bleaching process was significantly accelerated 1.32 times.*

## 1. INTRODUCTION

Localized surface plasmon resonance (LSPR) arise from the collective oscillation of free charge carries in noble metal nano-structures driven by the electromagnetic field of incident light. This strong light-matter interaction generates locally enhanced electromagnetic field, which has spurred great interest for its application in enhanced optoelectronic phenomena. We had already reported that enhanced electrochromic (EC) properties were found by using a gold nano-rod array electrode (Au-NRM) and ITO electrode immobilized Au nano-island. [1-4] The relationships between the EC characteristics and the nano-structured electrodes were evaluated by using ITO electrode immobilized Au nano-island in the study.

## 2. EXPERIMENTAL

Au nano-island was deposited on ITO electrode by electrochemical reduction with constant voltage (1.0 V) and pulse voltage (from 7 V to 12 V), carried out using an aqueous solution of Au (I) trisodium disulphite and potassium sulfite at room temperature.

The poly(3,4-ethylenedioxithiophene) [PEDOT] films were immobilized on the ITO by an electropolymerization in the monomer and the acetonitrile solution.

Simple two-electrode devices with silicon O-ring (ex. [PEDOT / Au-nano-structured electrode] / [propylene carbonate and lithium perchlorate electrolyte solution] / [ITO transparent glass electrode]) were assembled to evaluate the transparent EC properties.

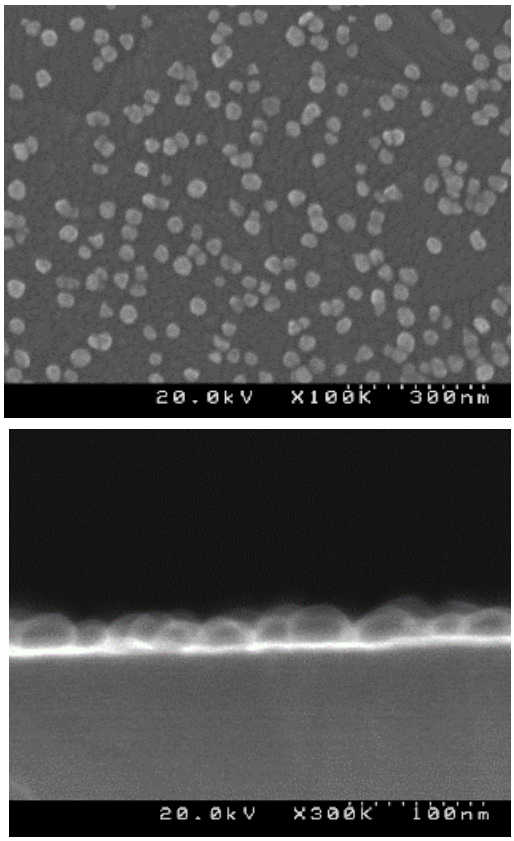


**Fig. 1 FE-SEM surface (a) and cross-sectional (b) images of the ITO electrode after electrodeposition of Au with pulse voltage application of -12 V.**

## 3.RESULTS AND DISCUSSION

Figure 1 showed FE-SEM images of the ITO surface view and the cross-sectional view after Au electro-deposition with a pulse voltage. Spherical Au nano-structures were observed on the ITO surface. As the result in size measurement, the distribution of the particle size was well uniform and the diameter was about 40 - 50 nm. The product electrode (Au-ITO) showed plasmon scattering characteristics on the transmittance spectrum. The absorption maximum of the Au-ITO was observed at the wavelength of around 580 nm. The peak wavelength and transmittance of the Au-ITO can be controlled independently by our procedures with

pulse voltage. Figure 2 shows changes in the transmittance spectrum of the PEDOT / Au-ITO (prepared by pulse voltage of -7 V) device induced by applied voltage switching between +2.5 V and –2.5 V. The difference in the EC color change at

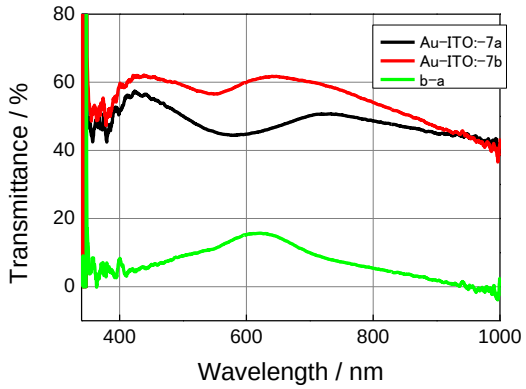


**Fig. 2 Changes in transmittance spectrum of Au-ITO device induced by DC voltage switching between -2.5 V and +2.5 V.**

the wavelength of 580 nm was 15.6%, which was from the PEDOT/Au-ITO (obtained with pulse voltage of -7 V). The difference in the color change can be seen by human eye. Figure 3 shows the difference spectra (between bleached state and coloured state) obtained from EC devices with Au-ITO formed by each pulse voltage. The maximum difference was obtained from that with Au-ITO formed by -12 V, and the value was 115% compared with moral ITO. Since the diameter of Au nano-particle and the wavelength of the plasmon scattering were approximately same as each electrode, this differences in the plasmon enhancement were probably taken place from difference in the number of the nano-particles or the contact area with PEDOT.

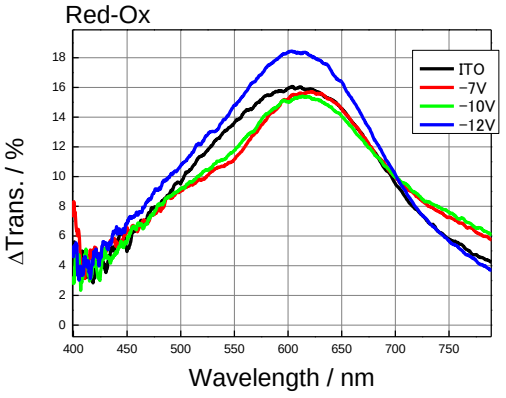


**Fig. 3 Difference spectra for PEDOT/Au-ITO devices induced by polarity inversion of applied voltage (2.5 V).**

In the EC device with Au-ITO formed by pulse voltage of -7 V, the EC response time was quite fast: 0.26 s for colouring and less than 0.1 s for bleaching. For the ITO device, the colouring was for 0.34 s and the bleaching was for less than 0.1 s. This result indicates that the response time (colouring) will be about 76% by using the Au-ITO compared to the ITO. Thus, a considerable acceleration of the EC change of PEDOT was achieved using the Au-ITO. This difference is probably from the dielectric-metal-dielectric (DMD) structures of the PEDOT/Au/PEDOT.

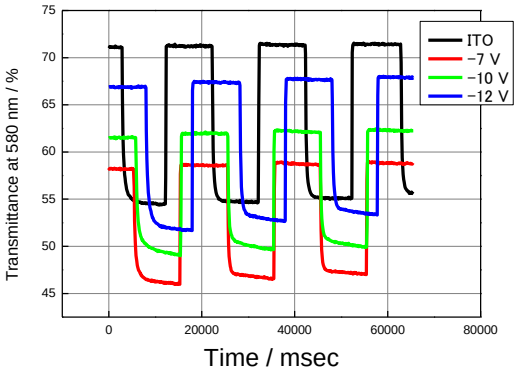


**Fig. 4 Time courses of transmittance at 580 nm for PEDOT/Au-ITO devices induced by polarity inversion of applied voltage (2.5 V).**

Table1 Response time (for 70 % change)

| | Ox-Red -2.5V (Sec) | Red-Ox +2.5V (Sec) |
|---|---|---|
| ITO | 0.338 | 0.064 |
| Au-ITO: -7 V | 0.256 | 0.091 |
| Au-ITO: -10 V | 0.276 | 0.081 |
| Au-ITO: -12 V | 0.356 | 0.106 |

## 6. REFERENCES

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