Nanoparticle Film Based Mechanoplasmonic Sensors for Wearable Strain Applications of Human-Motion Monitoring

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1. Introduction

Recently, electronic devices with stretchable features have received much attention because of the huge promises of strain sensors for human motion monitoring. Flexible strain sensors can monitor large mechanical deformations exceeding commercial electric strain sensors. Similarity, the mechanical method is known as one of external field control of SPRs, which provides an alternative while promising approach for mechano-plasmonic devices.

In this work, we aim to investigate operating mechanism, strain sensing activities and demonstration of stretchable strain sensors by human motion monitoring. Our group has implemented the structural and chemical control of the plasmonic properties of assembled films of Sn-doped In_2O_3 nanoparticles (ITO-NP films). Herein, we propose mechanical applications as dynamic control of plasmonic properties of the ITO-NP films for optical strain sensing techniques. In particularly, the ITO-NP films show highly resonant reflections in the IR range as consequences of optical properties as metamaterials, which are used as optical probes of strain detection. We report the challenges in the use of flexible skin-mountable and wearable sensors as the potential applications of flexible strain sensors using the SPRs of ITO-NP films.

2. Results and Discussion

Figure 1(a) shows reflectance spectra of the NP film placed on a PDMS substrate sheet measured under different applied strains (ε) from 0 to 50%. The total reflectance gradually decreased with an increase in applied strain, which was observed following with blueshifts of two resonances (peaks I and II). Herein, the electrical field of the incident light was parallel to the loading direction [inset of Figure 1(b))]. Reflectance changes at peaks I and II exhibited linear manners, relating to the strain - stress relations generated in the strained NP film. In addition, we observed optical anisotropy in reflectance change of the strained NP film, suggesting formation of anisotropic surface morphologies in the strained NP film. Actually, the anisotropic fragment structures were observed by high-resolution optical microscopy [Figures 1(c) and 1(d)]. The fragments played a key role in determining the optical properties.

Next, we demonstrated the flexibility of the optical strain sensor as a wearable device. Finger movement is a representative portion of wearable strain measurements. We attached the NP film to the joint part of the index finger using a glove with an adhesive tape to monitor human motion in real time. The spectral changes of the NP film were observed at different finger-bending angles [Figures 2(a) - 2(c)]. Figure 2(d) shows the reflectance spectra of the NP film as a function of the bending angle (α) measured by

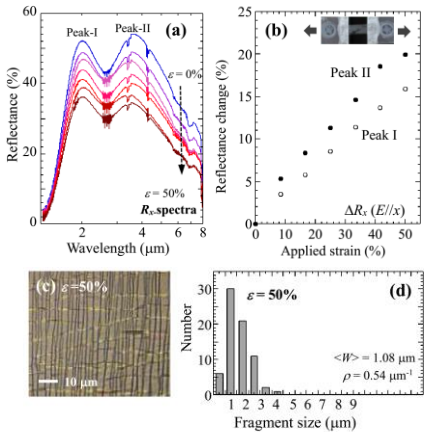

Figure .1 (a) Reflectance spectra as a function of applied strain. (b) Reflectance changes in resonant peaks I and II as a function of applied strain. (c) Optical surface image and histogram of fragment sizes of the NP film under an applied strain of 50%.

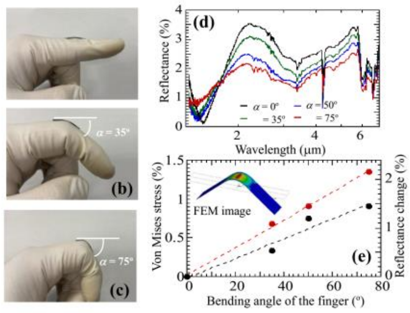

Figure 2. Images of the bending angles (α) of the index finger at (a) 0°, (b) 50°, and (c) 75°. (d) Reflectance spectra of the ITO NP film at different bending angles. (e) Relationship between the change in reflectance and von Mises stress as a function of the bending angle. Inset represents a simulated von Mises stress image on the joint part of the index finger at a bending angle of 75°.

placing the index finger. As the bending angle increased from 0° to 75°, the reflectance gradually decreased with a peak shift to the region with a shorter wavelength, relating to an increase in mechanical deformation. This spectral change was related to the stress distribution on the finger. The correlation between the stress and reflectance revealed that the NP film could detect the mechanical deformation of a human motion such as finger flexion.

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