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Letter

ZnO based UV detectors with Surface Plasmon Polariton enhancement on responsivity

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ABSTRACT

We have fabricated Surface Plasmon Polariton (SPP) enhanced ZnO based Metal–Semiconductor–Metal (MSM) photoconductive UV detectors with the introduction of Ag nanoparticles. The absorption spectra show two SPP resonance peaks located at 321 nm and 389 nm, respectively. Annealing in Ar atmosphere leads to a red-shift for the long wavelength peak due to an increase of the average size of Ag particles and congregation of them. The experiment data agrees well with the computing result based on Mie theory. And the responsivity enhancement is demonstrated by the fact that the peak responsivity (at 350 nm) increases by more than 100 times, from 472 mA W^{-1} to 51.3 A W^{-1}.

1. Introduction

UV photodetectors have attracted great researching interest for their potential application in missile alarm, flame detection, chemical and biological sensors and space communications [1–4]. ZnO appears to be a good alternative for UV photodetectors because of its wide band gap, ease of manufacturing, environment friendliness and low cost [5]. It is very important to improve the responsivity of ZnO based UV photodetectors in order to replace widely-used photomultiplier tubes in light signal detection. Recently, it has been found that the responsivity of GaN based UV photodetectors can be enhanced by Surface Plasmon Polariton (SPP) due to the introduction of Ag nanoparticles [6]. As we know, SPP is electro-magnetic wave coupled to free electron oscillations in a metal [7]. And metal nanoparticles scattering results in greater optical absorption in the photo sensitive layer [8]. The scattering cross section can be greatly enhanced by interaction between the incident light and nanoparticles through resonant excitation of SPP [9]. Ag nanoparticles are frequently used in the application of SPP enhancement [6,10]. In previous years, responsivity enhancement by SPP has only been demonstrated on GaN based photodetectors to the best of our knowledge. And recently, Hu et al. reported the improvement of ZnO/Si photodiode by embedding of Ag particles [11]. In addition, Tong et al. fabricated nanoplasmonic enhanced ZnO/Si heterojunction photodetectors [12]. However, they did not emphasize the responsivity enhancement of the ZnO based MSM UV detector with the introduction of Ag nanoparticles which have been prepared by a chemical method. Here we report our demonstration of SPP enhancement on responsivity of ZnO based MSM photoconductive UV detectors. These detectors are based on Ohmic type metal–semiconductor contact instead of Schottky type. We have fabricated high-performance ZnO based MSM UV photodetectors with Ag nanoparticles positioned atop on ZnO film. And Scanning Electron Microscopy and UV–Vis absorption spectra measurements were employed to characterize the ZnO film with Ag nanoparticles on it. Responsivity enhancement of ZnO based UV photodetectors with the introduction of Ag nanoparticles was observed. The mechanism of Ag nanoparticle enhancement was discussed according to Mie scattering theory [9,13].

2. Methodology

The high quality ZnO thin film used to fabricate SPP enhanced MSM UV photodetector was deposited by radio frequency magnetron sputtering on quartz substrate. The details are discussed elsewhere [14].

After sputtering the next step is deposition of Al electrode. Then we prepared Ag nanoparticles on the as-grown ZnO film. We used sodium citrate solution to react with silver nitrate solution to acquire Ag nanoparticle solution. In our experiments, the silver

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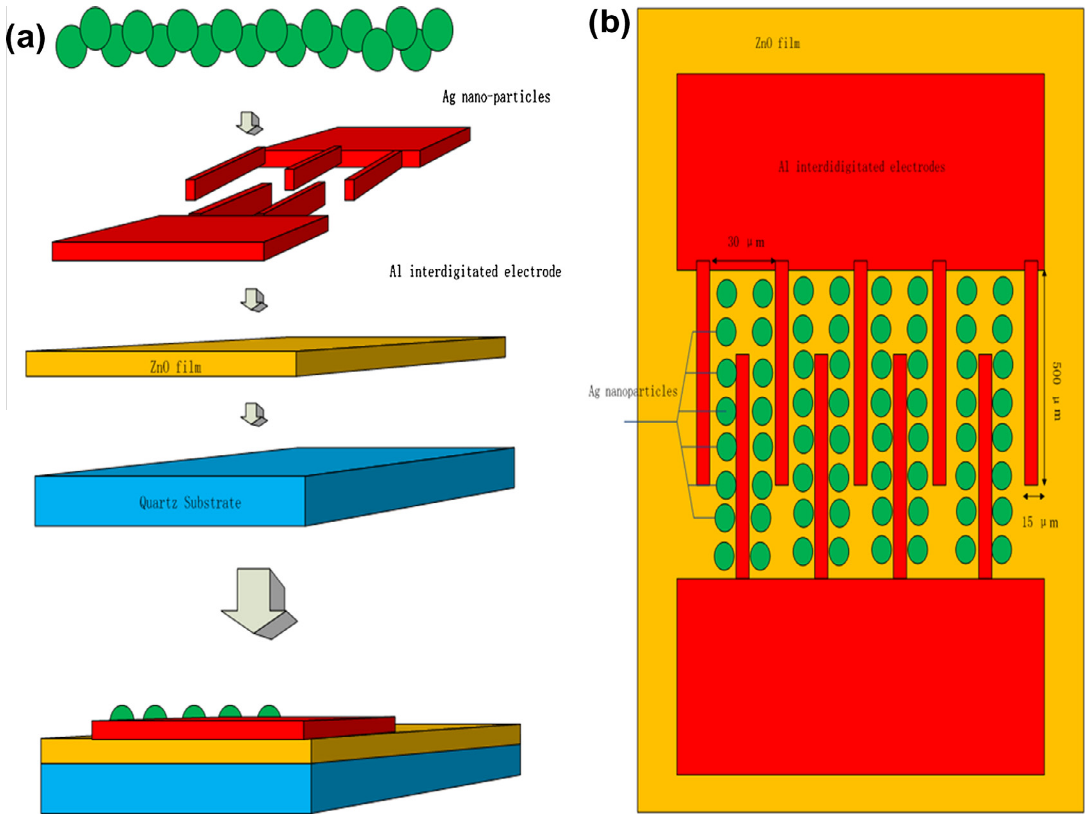

Fig. 1. (a) The vertical structure and fabrication order of the detectors and (b) the horizontal structure of the detectors.

nanoparticle solution was spin-coated on the as-grown ZnO film, and then the solvent was evaporated and silver nanoparticles were left on the film. The spin rate was 450 r/min and it lasted 18 s. After the deposition, some of the samples were annealed at 500 °C for 5 min. Ar gas was used to protect Ag nanoparticles from oxidation, the flow rate was 30 sccm, and the pressure in the annealing chamber was kept at 2 Pa.

SPP enhanced MSM UV photodetectors was fabricated by the standard semiconductor planar process. Fig. 1 (a) shows the whole fabrication process of the photo-detector and (b) the geometry of the Al electrodes.

3. Result and discussion

The SEM images of Ag nanoparticles are shown in Fig. 2. The left one is the sample without annealing, and the right one is the sample after annealing. It can be seen from the images that small Ag nanoparticles recrystallized and formed bigger ones after annealing process. The average size of those particles without annealing is about 128 nm and the average size of Ag nanoparticles increased to 141 nm after annealing. Furthermore, Ag nanoparticles are more densely distributed after annealing.

We used the model based on Mie theory. In order to simplify the model, it is usually assumed that the particles and the medium are continuous and homogeneous, which is appropriate and applicable in most cases. Based on Ehrenrich and Philipp [15] and Taneja's et al. [16] discussion, we obtain

$$\varepsilon_r(\omega) = 1 + \frac{f_1\omega_1^2(\omega_1^2-\omega^2)}{(\omega_1^2-\omega^2)^2+(\omega\gamma)^2} - \frac{\omega_p^2}{\omega^2+\gamma^2} \quad (1)$$

$$\varepsilon_i(\omega) = -\frac{f_1\gamma\omega_1^2\omega}{(\omega_1^2-\omega^2)^2+(\omega\gamma)^2} - \frac{\omega_p^2\gamma}{\omega(\omega^2+\gamma^2)} \quad (2)$$

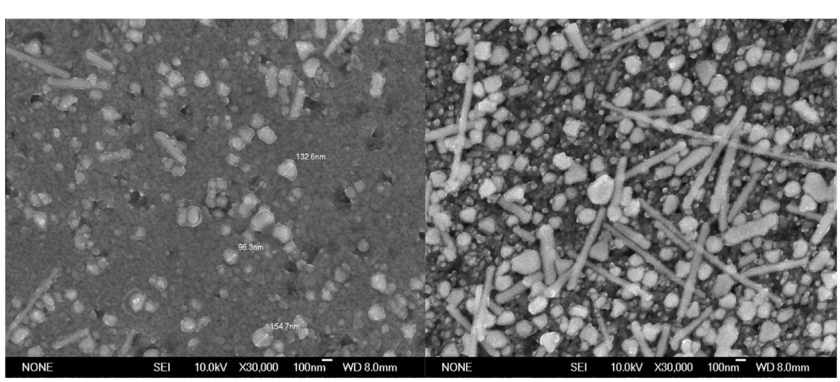

Fig. 2. The SEM image of ZnO film with Ag nanoparticles on it before (left) and after (right) annealing.