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The relation of structure and dispersion to amorphous silicon silver thin films

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A R T I C L E I N F O

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A B S T R A C T

Silver/amorphous silicon (Ag/a-Si) memristor has attracted extensive attention as a candidate for next-generation nonvolatile memories. The optical constant variations of a-Si layer during switching procedure, which are the key for Ag/a-Si memristor to be used in optical applications, have not been clarified yet. To take a further understanding on the optical feathers of Ag/a-Si memristor, here we report the microstructure, resistivity and dispersion relation of amorphous silicon silver (a-$Si_{1-x}Ag_x$) thin films prepared by co-sputtering. Ag nanocrystals are observed in the films with size similar to the Ag filament in memristor, and the obtained resistivities of the films march the typical ON/OFF ratio of memristor. Furthermore, both the film's refraction index and extinction coefficient increase with Ag concentration, suggesting that Ag/a-Si memristor combining with silicon waveguide could be applied in optical switch at 1300 and 1550 nm.

1. Introduction

Silver/amorphous silicon (Ag/a-Si) memristor consisting of Ag/a-Si/p-type silicon (*p*-Si) layered structure has attracted extensive attention in microelectronic field as a promising candidate for the next-generation nonvolatile memories with excellent miniaturization potential, sub-ns operation speed and high-endurance [1–3]. The resistance switching behavior of the device is realized in terms of silver filament formation (dissolution) in the a-Si matrix at positive (negative) applied voltage. During this resistance switching procedure, optical properties of the a-Si layer could be varied as well, suggesting potential optical applications of Ag/a-Si memristor. Recently, Ag/a-Si memristor based optical readout memories [4] and optical switch [5] have been reported. By fabricating memristor on p-Si waveguide, the a-Si layer can serve as both resistance switching medium of memristor and cladding of waveguide. Thus the optical property changes of a-Si layer in switching process would modulate the propagating light in waveguide. However, the exact dispersion relation of the a-Si layer containing Ag filament has not been clarified in these reports yet. Meanwhile, since the a-Si layer contained with Ag filament is actually a kind of a-Si thin film embedded with Ag nanoparticles [6] and the Ag diffusion in a-Si matrix is nonuniform [7], the study of amorphous silicon silver (a-$Si_{1-x}Ag_x$) thin film with different Ag concentrations will be helpful to further understand the optical properties of Ag/a-Si memristor. Nevertheless, there are only a few literatures about the optical properties of a-$Si_{1-x}Ag_x$ thin film so far and most of them are focused on the plasma resonance absorption [8–10]. The dispersion relation of optical constants, to our best knowledge, has not been reported yet, and this feather is crucial for the design and optimization of optical devices. In this paper, the microstructure, resistivity and dispersion relation of a-$Si_{1-x}Ag_x$ thin films are studied, and the variations of optical constants at 1300 and 1550 nm, the telecommunication windows, are especially discussed.

2. Experimental procedure

The a-$Si_{1-x}Ag_x$ thin films were deposited by co-sputtering on glass substrates. Deposition conditions were coincident with our early work [11], except that several Ag chips (99.99%) were fixed on the Si target (99.999%) and H_2 flow was not introduced here. The nominal Ag concentration, varying from 2% to 32%, was estimated by the target coverage proportion of Ag chips and the sputtering yields. The test conditions of X-ray diffraction (XRD), high resolution transmission electron microscope (HRTEM), Raman and resistivity, were the same as Ref [12]. The dispersion relation was carried out by spectroscopic ellipsometry (SE) method with SENTECH SE850 ellipsometer.

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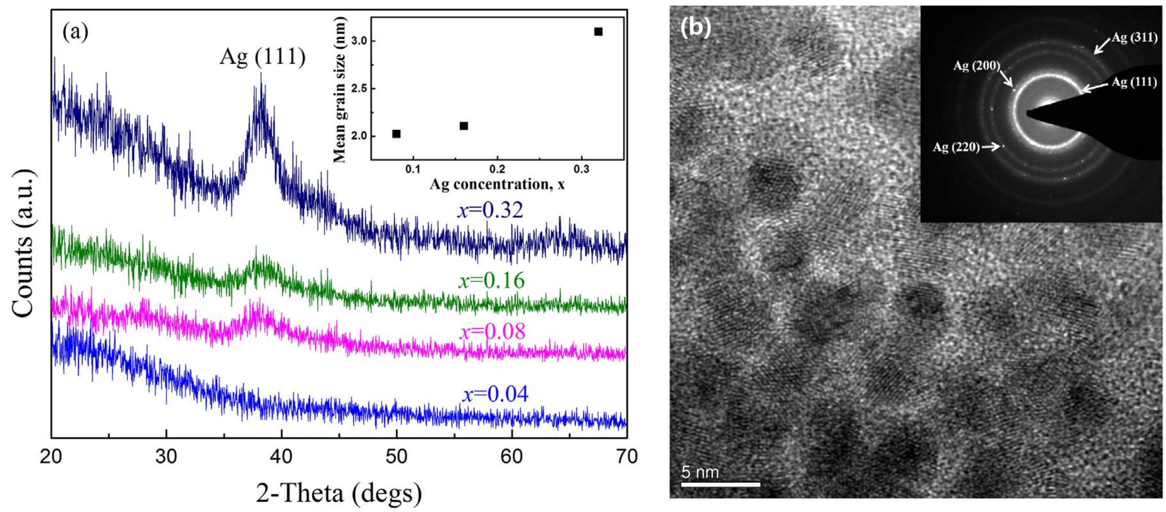

Fig. 1. XRD spectra (a) and TEM image (b) of a-$Si_{1-x}Ag_x$ thin films. The inset of (a) shows the mean size of Ag nanocrystals and the inset of (b) shows the related diffraction pattern.

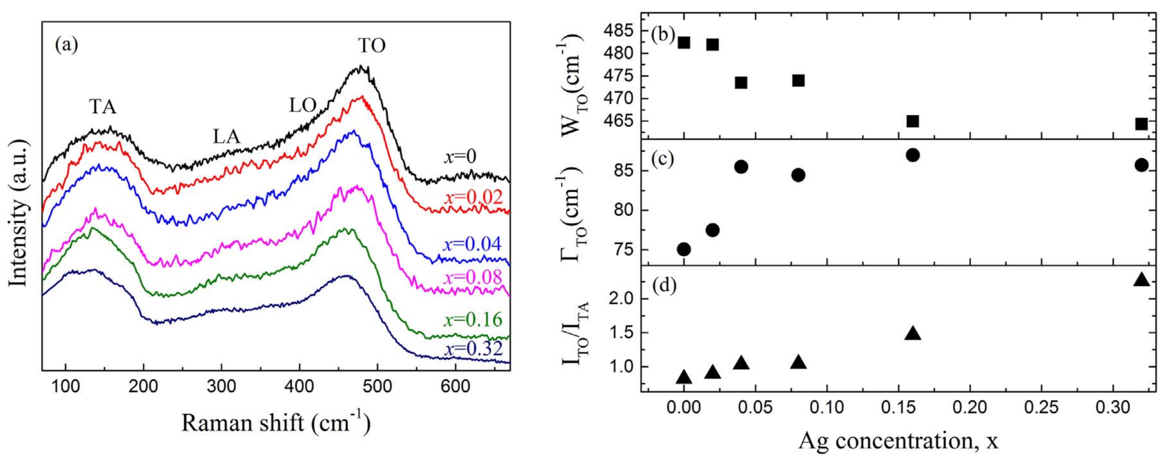

Fig. 2. Raman spectra (a) and Raman parameter variation (b) of a-$Si_{1-x}Ag_x$ thin films.

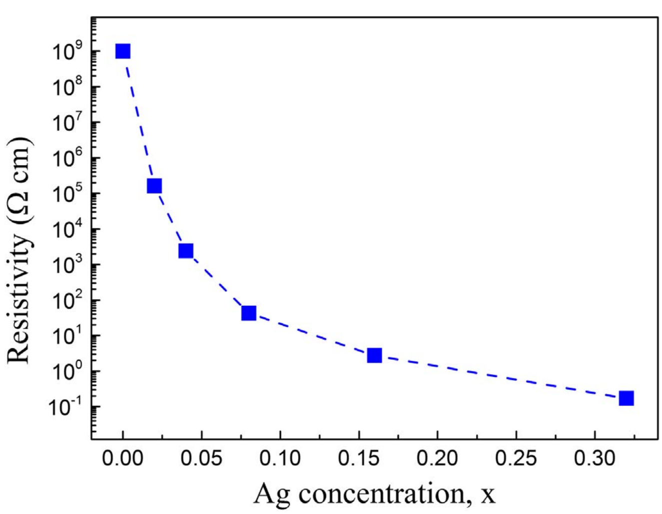

Fig. 3. Resistivity of a-$Si_{1-x}Ag_x$ thin films.

3. Results and discussions

As a eutectic metal, silver may form nanocrystals embedded in a-Si matrix. Fig. 1(a) shows the XRD spectra of a-$Si_{1-x}Ag_x$ thin films with different Ag concentration. The peak at about 38.2° assigned to Ag (111) is observed with Ag concentration higher than 8%, confirming the existence of Ag nanocrystals. But for samples with Ag concentration lower than 4%, this peak could not be recognized possibly due to the relatively low fraction of Ag nanocrystals which is below the detection limit of XRD instrument. According to Scherrer formula, the mean size of Ag nanocrystals is calculated and depicted in the inset of Fig. 1(a). This size is very close to that of Ag nanocrystals formed in the Ag/a-Si memristor at positive voltage (1–4 nm) [6]. Moreover, HRTEM photographs are taken to further confirm the size of Ag nanocrystals. Fig. 1 (b) shows the image of a-$Si_{1-x}Ag_x$ thin films with Ag concentration fixed at 32%. Plenty of small spherical nanocrystals with diameters about 3–4 nm are observed densely embedded in amorphous matrix. The diffraction pattern, as shown in the inset of Fig. 1(b), consists of a series of poly-crystal rings and a halo ring belonging to Ag nanocrystals and a-Si, respectively. These results indicate that the microstructure of our a-$Si_{1-x}Ag_x$ thin films prepared by co-sputtering are similar to that of the Ag filament contained a-Si layer in memristor.

Raman scattering is employed to estimate the structural variation of a-$Si_{1-x}Ag_x$ thin films with different Ag concentration. Since Raman peaks are forbidden for silver because of crystal symmetry, only the Raman spectra of a-Si matrix are shown in Fig. 2(a). The typical Raman spectrum of a-Si contains transverse acoustical (TA), longitudinal acoustical (LA), longitudinal optical