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Impacts of ITO interlayer thickness on metal/n-Ge contacts

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ABSTRACT

The dependence of Schottky barrier height (SBH) of metal/ITO/n-Ge contacts on ITO interlayer thickness is experimentally investigated. The SBH of metal/ITO/n-Ge contacts for various metal electrodes of Al, Cu, and Pt is estimated. It is found that the SBH of metal/ITO/n-Ge contacts decreases with increase of ITO thickness from 0 to 4 nm, and the dependence of SBH on the metal work function is weak. When the thickness of ITO is larger than 4 nm, ohmic metal/ITO/n-Ge contacts are obtained for different metal electrode. The formation of ohmic contact can be ascribed to high carrier concentration of ITO itself and the excellent passivation for Ge surface. The interdiffusion between cap metal and ITO should be responsible for the modulation of SBH of metal/ITO/n-Ge contacts.

1. Introduction

Benefited from its higher carrier mobility and large optical absorption coefficient at the wavelength for optical communication, germanium (Ge) is considered as one of the most promising materials in future microelectronic devices [1]. However, there are some obstacles need to be addressed before Ge can become a forefront element in advanced CMOS technology. One of the hurdles is to form good ohmic contact with n-Ge for realizing high performance Ge n-MOSFETs. It is mostly attributed to high electron Schottky barrier height (SBH) when metals contact with n-Ge, derived from the strong Fermi-level pinning (FLP) at the vicinity of the valence band maximum of Ge [2,3]. The resulting large series resistance severely deteriorates the performance of Ge devices. Recent experiments have demonstrated modulation of the effective SBH of metal/n-Ge contact by inserting an interfacial layer, such as AlO_x [4], ZnO [5], $Ge_{1-x}Sn_x$ [6], GeO_xN_y [7], $GeSnO_x$ [8], TiO_2 [9], TiN [10], WN_x [11] between the metal and n-Ge. Many kinds of interlayers can alleviate Fermi-level pinning effect and produce ohmic contacts on n-Ge. However, the metal interlayer semiconductor contact resistance depends not only on SBH but also on the series tunneling resistance introduced by the interlayer. Thus, a doped oxide interlayer is needed to overcome this limitation [5,12,13]. Specifically, ITO has been shown to give low resistance contacts due to its low conduction band offset with Ge and high doping concentration [12]. High performing ITO/Ge heterojunction photodetector have been report by ITO contact with p-Ge [14]. It is report that the electron affinity χ of ITO and Ge is 4.19 eV and 4.0 eV, respectively [12]. Thus, a small ΔEc of -0.19 eV between ITO and n-Ge can be acquired. Besides, benefited from its low resistivity, series resistance derived from ITO interlayer can be neglected. Namely, as an interlayer between the metal and n-Ge, ITO interlayer can produce ohmic contacts on n-Ge while avoiding introducing serious series resistance. However, the mechanisms of the modulations of SBHs for metal/ITO/n-Ge have not been systematically studied yet.

In this work, metal/ITO/n-Ge contacts are prepared to investigate the modulation of SBHs by varying the thickness of the ITO interlayers. To clarify the mechanism for the modulation of SBH in metal/ITO/n-Ge contacts, various metals with different work functions, were used as the top electrode for the contacts. It is found that the SBH of metal/ITO/n-Ge contacts decreases with increase of ITO thickness from 0 to 4 nm. Besides, the dependence of SBH on the metal work function is weak for metal/ITO/n-Ge contacts. Meanwhile, the ITO has a wide range of thicknesses (4–50 nm) to retain ohmic contact compared with other insulator materials. Possible reasons for the modulation of the SBHs of metal/ITO/n-Ge contacts are discussed.

2. Experimental

The n-type Ge(100) wafers with a phosphorus doping concentration of 2×10^{16} cm^{-3} were circularly degreased in an ultrasonic bath of acetone and ethanol, then immersed in a hydrofluoric acid solution (HF: H_2O = 1: 50) to remove the native oxide, finally rinsed with deionized water, and blown dry with nitrogen. After cleanout, the wafers were immediately loaded into the well-controlled

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sputtering system in high purity Ar ambient at room temperature, and a shadow mask with circular patterns was fixed on the front side of the n-Ge substrate to form metal contacts with an area of 0.005 cm^2. ITO films with various thicknesses (0–50 nm) followed by 300-nm-thick Al, Cu, or Pt were deposited on the n-Ge by DC magnetron sputtering. The samples without ITO layer were also prepared for comparison. ITO films were prepared on n-Ge substrates by DC magnetron sputtering using an ITO target (purity: 99.99%, diameter: 60 mm, In_2O_3: SnO_2 = 90: 10 wt%) at room temperature. The base vacuum pressure of the sputtering system is 1.0×10^{-4} Pa. During the sputtering process, the deposition pressure was maintained at 0.3 Pa, and the DC power was kept at 33 W. ITO thickness was controlled by the sputtering time with a deposition rate of 0.08 nm/s. Finally, 300 nm of Al was deposited on the backside by DC magnetron sputtering of all the samples to get a good ohmic contact.

The surface morphology was analyzed by atom force microscopy (AFM, Seiku Instruments, SPI4000/SPA-400) in a tapping mode. The elemental composition of ITO film was characterized by Auger electron spectroscopy (PHI 660). The low-temperature I-V characteristics were acquired by a Keithley 2611B source/meter and Janis CCS100/204 helium circulation thermostat. The elemental distribution for metal/ITO/n-Ge contact was analyzed by scan transmission electron microscopy (JEM2100), the diameter for STEM beam scan transmission electron microscopy was 0.38 nm.

3. Results and discussions

The atomic force microscopy (AFM) images with a scanned area of 10×10 μm^2 of different thick of ITO layer deposited on Ge substrate are shown in Fig. 1. As shown in Fig. 1, the surface of ITO is very smooth and the root-mean-square surface roughness is less than 0.5 nm, slightly larger than that of the clean-bare Ge. Auger electron spectroscopy was performed for 30 nm-thick ITO film on Ge substrate to study the composition of ITO. To avoid contamination, sample was tested after etched by 10 nm and 20 nm. As shown in Fig. 2, the atomic percentage of O, In, and Sn for ITO film is about 53%, 44%, and 3%, respectively.

The electrical properties of the samples with Al/ITO/n-Ge contacts were characterized on the basis of room temperature current density–voltage (J–V) characteristics as shown in Fig. 3(a). The insertion of ITO interlayer lowers the effective Φ_n of Al/n-Ge contact resulting in an increase in forward and reverse current densities. Fig. 3(b) shows forward and reverse current densities of Al/ITO/n-Ge at 0.1 V bias, with an increase in the ITO thickness from 0 to 4 nm. The significant increase of current density suggests that the tunneling barrier is greatly affected by the thickness of ITO for metal/ITO/n-Ge contacts.

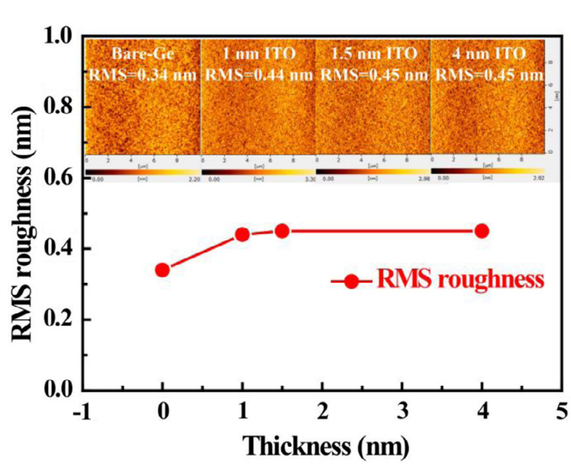

Fig. 1. Thickness dependence of RMS roughness of ITO films on Ge. The inset displays the AFM images of ITO films on Ge.

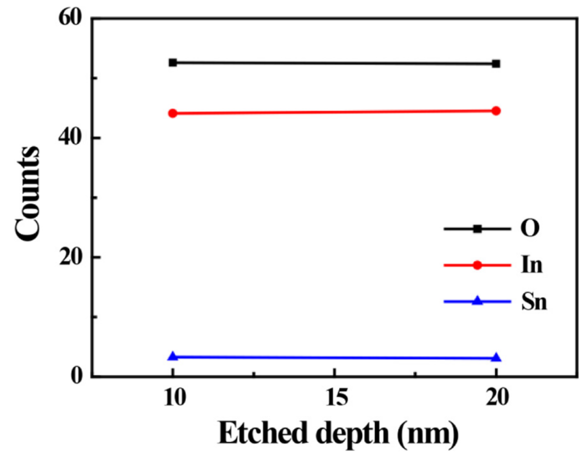

Fig. 2. Atomic depth profile of O, In, and Sn in ITO film deposited on Ge substrate.

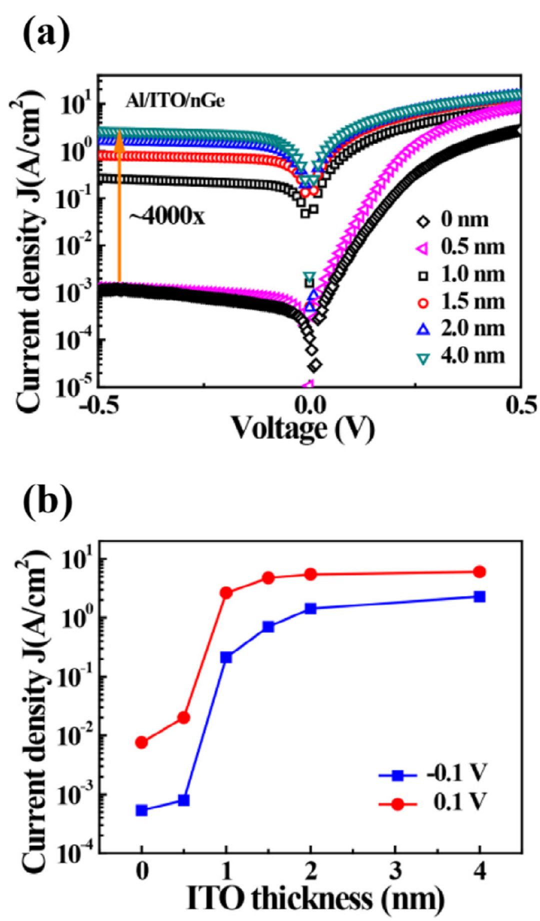

Fig. 3. (a) Room temperature J–V characteristics for Al/ITO/n-Ge contacts. (b) Dependence of forward and reverse current densities at low bias (±0.1 V) for Al/ITO/n-Ge contacts on ITO thickness.

Fig. 4(a) and (b) shows the low-temperature J–V characteristics of Al/ITO/n-Ge contacts with ITO interlayer thickness of 1 and 4 nm, respectively. SBHs of the diodes could be extracted from temperature dependent J-V characteristics using the activation energy method [15]. According to the thermionic emission theory,