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Nonalloyed transparent ohmic contact of indium tin oxide to p-type $Si_{0.8}Ge_{0.2}$

J.D. Hwang [a,*], W.T. Chang [a], K.H. Hseih [a], G.H. Yang [a], C.Y. Wu [a], P.S. Chen [b]

[a] *Department of Electrical Engineering, Da-Yeh University, Da-Tsuen, Changhua, Taiwan, R.O.C.*
[b] *Department of Materials Science and Engineering, Ming Hsin Uinversity of Science and Technology, Taiwan, R.O.C.*

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Abstract

Nonalloyed transparent ohmic contacts of indium tin oxide (ITO) to p-type $Si_{0.8}Ge_{0.2}$ layer with and without a Si-capping layer were examined. The ITO films and the p-type $Si_{0.8}Ge_{0.2}$ layers were deposited by using sputtering and ultrahigh-vacuum chemical vapor deposition, respectively. It is shown that the ITO/p-type $Si_{0.8}Ge_{0.2}$ contact structure exhibits a specific contact resistance of 2.26×10^{-5} Ω cm^2 as compared to that of 2.78×10^{-2} Ω cm^2 for the ITO/Si/p-type $Si_{0.8}Ge_{0.2}$ contact structure. Possible mechanisms are proposed. The ITO film exhibits a transmittance more than 85% within a wavelength range from 800 to 1400 nm. Therefore, the ITO film has a high potential for fabricating near infrared optoelectronic devices using $Si_{1-x}Ge_x$ material.

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Keywords: Silicon–germanium; Indium tin oxide; Resistivity; Sputtering

1. Introduction

$Si_{1-x}Ge_x$-based optoelectronic devices, such as Schottky-barrier detectors [1,2], pin photodiodes [3,4] and SiGe/Si heterojunction internal photoemission detectors [5,6], are now commercially available for infrared applications. The ohmic contact resistance of a transparent electrode is the most critical issue that will ultimately determine the functional success of the $Si_{1-x}Ge_x$-based optoelectronic devices. It is known that higher ohmic contact and series resistances reduce the performance of the optoelectronic devices, notably device response speed. On the other hand, lower transparency of electrode material would inevitably absorb incident photons and degrade the responsivity of the optoelectronic devices. Ohmic contact on SiGe using metals Ti, W, Pt, or Co has been reported [7–9]. However, these ohmic contact electrodes were prepared indirectly onto SiGe layers through Si-capping layers to form refractory silicides in high-temperature alloying. It was reported [10,11] that the interfacial reaction of metal on an epitaxial $Si_{1-x}Ge_x$ layer would involve a preferential reaction with Si, resulting in Ge segregation and Fermi level pinning. Thus, the Si-capping layer was used as a sacrificial layer to obtain a silicide contact to the $Si_{1-x}Ge_x$ layer. However, the non-transparency of the refractory silicides will seriously retard the entrance of incident photons, and thereby degrade the responsivity of the SiGe-based optoelectronic devices. It is well known that ITO is a good transparent electrode with a low resistivity of 1×10^{-4} Ω cm. The ITO electrode has been widely used in GaN-based optoelectronic devices and good results were obtained [12–14]. In this work, a nonalloyed ITO ohmic contact to SiGe is proposed for the first time to our knowledge. In our work, a low specific contact resistance of 2.26×10^{-5} Ω cm^2 is found in an ITO/p-$Si_{1-x}Ge_x$ system without a Si-capping layer.

2. Experiments

The n-type silicon substrates were cleaned using organic solvents and then $HF:H_2O$ (1 : 5) solution to remove native

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[*] Corresponding author. Tel.: +886 4 8511888x2190; fax: +886 4 8511245.
E-mail address: jundar@mail.dyu.edu.tw (J.D. Hwang).

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oxide on the silicon substrate. The strained $Si_{0.8}Ge_{0.2}$ layer was then grown on the (100) n-Si substrate by an ultrahigh-vacuum chemical vapor deposition (UHVCVD) system, in which SiH_4 and GeH_4 were used as the sources of Si and Ge, respectively, and a growth temperature of 550 °C was used. The thickness of Si-capping layer was 30 nm, which was deposited by UHVCVD also. Hall-effect measurement was conducted on the as-grown strained $Si_{0.8}Ge_{0.2}$ sample and a carrier concentration of 3×10^{16} cm^{-3} was measured. Subsequently, the as-grown $Si_{0.8}Ge_{0.2}$sample with or without a Si-capping layer and glass substrate were loaded into a radio frequency sputtering system with no dc-bias for depositing an ITO film by using ITO target (90% In_2O_3 + 10% SnO_2) and the sputtering was carried out with a substrate temperature of 25 °C, a pure Ar gas flow of 110 sccm, a pressure of 1.33 Pa, and a plasma power density of 1.48 W/cm^2. From profilometry measurements, the thickness of the as-grown $Si_{0.8}Ge_{0.2}$ layer and the as-deposited ITO films were 150 and 110 nm, respectively. Device isolation was made to form a mesa structure using plasma etching.

In order to investigate the thermal stability of ITO/SiGe contact system, some ITO/glass and ITO/p-$Si_{0.8}Ge_{0.2}$ samples were annealed at 400~600 °C in N_2 atmosphere. Sheet resistance and transmittance of ITO films deposited on glass substrate under different annealing temperature were determined. The current–voltage ($I-V$) characteristics of the ITO/p-$Si_{0.8}Ge_{0.2}$ samples were measured by a HP-4155A semiconductor parameter analyzer. The X-ray diffraction pattern of as-grown and 600 °C annealed $Si_{0.8}Ge_{0.2}$layers was examined to understand the thermal effect on the structure.

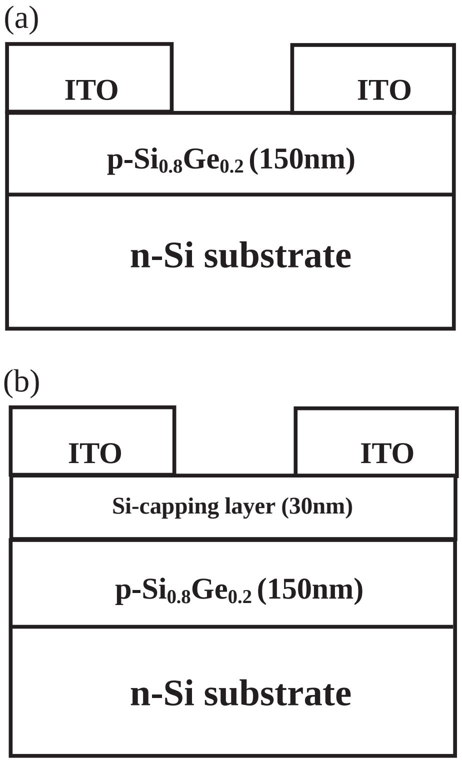

Fig. 1. The ITO contacts to p-$Si_{0.8}Ge_{0.2}$ layer with and without a Si-capping layer.

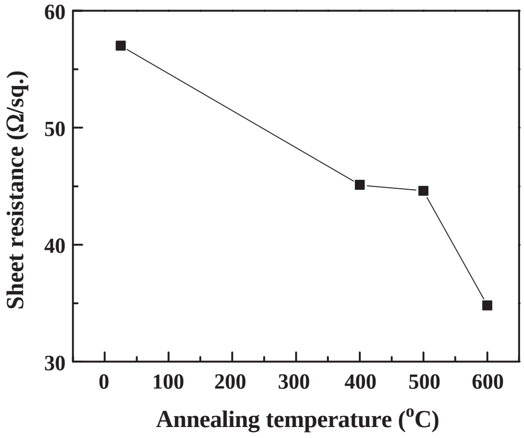

Fig. 2. Sheet resistances of ITO films on glass substrate with different annealing temperature.

3. Results and discussion

Fig. 1 shows the ITO contacts to the p-$Si_{0.8}Ge_{0.2}$ layers with and without the Si-capping layer. Firstly, sheet resistances of ITO/glass samples annealed at 400~600 °C are shown in Fig. 2. It shows that we could grow high quality ITO films from this sputtering system. Transmittance measurements were also conducted on our ITO film and the result is shown in Fig. 3. It is shown that within a wavelength range from 800 to 1400 nm, our as-deposited and 400 °C annealed ITO films demonstrate both transmittance of more than 85%, indicating that our ITO film has a high potential for fabricating near infrared optoelectronic devices using a low energy gap semiconductor material of $Si_{1-x}Ge_x$.

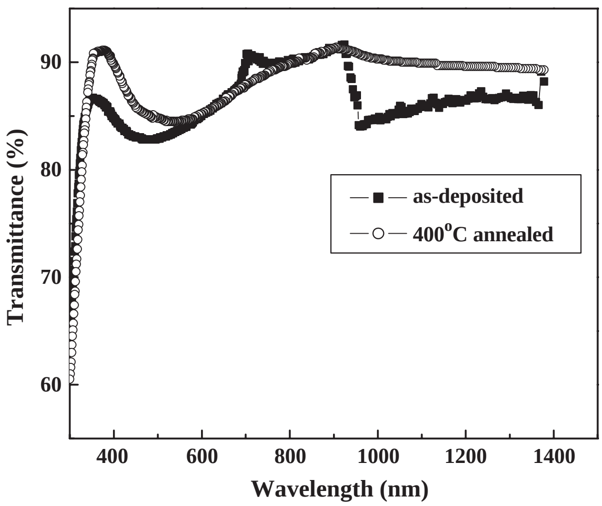

Fig. 3. Transmittance of sputtered ITO films with and without annealing.