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E-6-3 Functional Enhancement of Metal-Semiconductor-Metal (MSM) Infrared Photodetectors on Heteroepitaxial SiGe-on-Si Using the Anodic Oxidation/Passivation Method

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INTRODUCTION

Silicon photonics is one of hot research topics these days, obviously due to a fact that a well-established silicon microelectronic device processing technology could be used to fabricate varieties of electronic and optical devices. Several silicon-based material systems have been thoroughly investigated [1]; however, silicon-germanium (SiGe) offers a tunable bandgap which significantly enhances its applicability for integrated optics. Due to the transparency of silicon for $\lambda > 1.2$ μm and therefore it is not appropriate for photodetection applications requiring the absorption wavelengths of 1.31 and 1.55 μm, $Si_{1-x}Ge_x$ certainly has an edge of a relative high absorption coefficient at these wavelengths. Since the bandgap of $Si_{1-x}Ge_x$ can be modulated from that of silicon to that of Ge (~0.8 eV), the detection spectrum of this material system will comfortably cover the wavelength detection range of 1.31–1.55 μm, making the fabrications of SiGe-based near-infrared photodiodes at these wavelengths a true reality [2-3].

To maximize the performance of SiGe/Si-based optoelectronic devices, incorporating a low thermal budget passivation step into the device fabrication process flow is usually required in order to minimize the number of surface state density. Conventional thermal oxidation of SiGe compounds above 600°C would result in Ge segregation along the oxide/SiGe interface [4] and relaxation of the strained SiGe lattice of the film epitaxially grown on *c*-Si [5]. High-temperature passivation techniques inevitably induce defects in the crystal lattice and also at the interfaces which significantly impact the electronic performance of the device. Therefore, several low thermal budget processes below 500°C were introduced in the past [5-8], including the low thermal budget anodic oxidation. The anodic technique is preferred over the others simply because it is a genuine low thermal budget process which could be carried out below 60°C and subsequent annealing step could be performed at temperatures below 450°C.

This work mainly focuses on using the anodic oxidation method to enhance the performance of SiGe/Si MSM photodetectors operating at the infrared spectrum. Specifically, we attempt to demonstrate the dark leakage current of these devices due to the presence of surface states on SiGe film could be substantially reduced if the film surface was passivated by the anodic oxide; this in turn would help to enhance the sensitivity of the detectors by boosting their corresponding photocurrent-to-dark current ratio. The x-ray diffraction (XRD), atomic force microscopy (AFM), Auger electron spectroscopy (AES), capacitance-voltage (C-V) method, current-voltage (I-V) study, and spectral analysis will be utilized altogether to characterize how the the SiGe film quality and functionality of SiGe MSM infrared photodetectors would be affected by using anodic oxidation method.

EXPERIMENTS

The SiGe samples were prepared epitaxially using ultrahigh vacuum chemical vapor deposition (UHVCVD) technique. The entire device structure consists of a 75-nm-thick SiGe buffer layer first grown on the p^--type silicon substrate, followed by the deposition of 280-nm-thick *i*-$Si_{0.68}Ge_{0.32}$ layer at 550°C. Two separate batches of MSM photodetectors were fabricated on heteroepitaxial SiGe-on-Si samples with and without (as the control sample) the prior treatment of anodic oxidation. The MSM photodetectors comprise of interdigitated fingers with dimensions of 10-μm-wide fingers and 10-μm spacing in between. Fig. 1 shows the Teflon anodic oxidation cell. The SiGe sample is fixed on the anode electrode, while the cathode electrode is inserted into the oxidation cell filled with 0.04 M KNO_3/ethylene glycol/0.3% H_2O electrolyte solution. Both anode and cathode electrodes were made up of platinum in order to prevent the solution from eroding the electrodes during the oxidation process. In addition, a DC power supply was used to provide the needed voltage and current. The electrolyte solution was kept stirring, while the

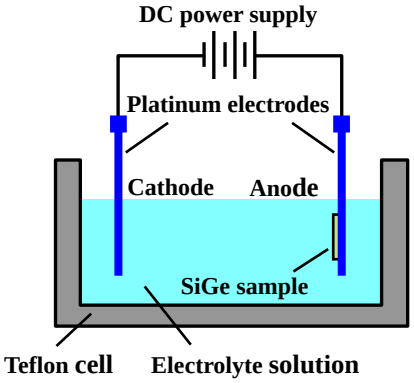

FIG. 1. A schematic drawing of the SiGe anodic oxidation cell.

temperature was controlled by a thermostat. To prepare samples ready for anodic oxidation, the SiGe-on-Si wafer was diced into pieces and each one with size of ~1 cm × 1 cm. Then, the backside of each sample was first polished before depositing 1500-Å-thick aluminum as contact electrode using the thermal evaporator. The polishing step

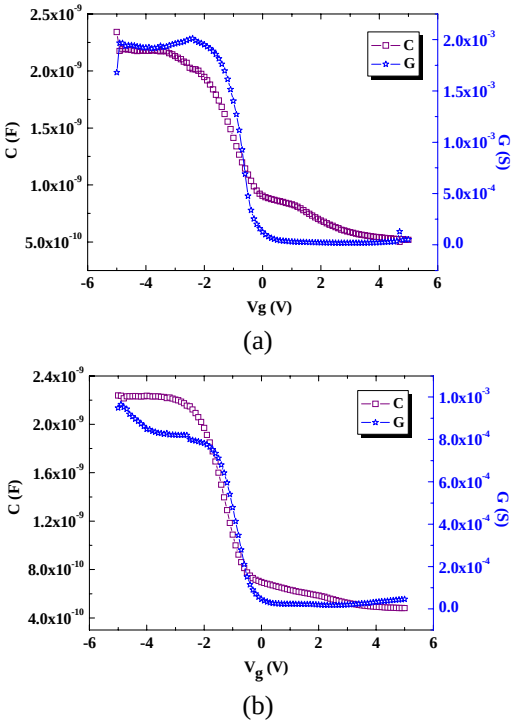

FIG. 2. The current-voltage (C-V) conductance method was applied to SiGe samples undergoing the prior anodic oxidation treatment with current density of (a) 1 mA/cm^2 and (b) 4 mA/cm^2, respectively.

was included to ensure backside ohmic contact was achieved with the platinum anode electrode. Three different current densities (4, 1, and 0.1 mA/cm^2) and 70-minute duration were attempted for all SiGe samples undergoing the anodic oxidation. Once the oxidation process was completed, the capacitance-voltage (C-V) conductance method was employed thereafter to determine the interface surface state densities, D_{it}, at the oxide/SiGe interface of oxidized SiGe samples [9].

RESULTS AND DISCUSSION

Figs. 2(a) and 2(b) show the current-voltage (C-V) conductance data gathered from SiGe samples undergoing the prior anodic oxidation treatment with the current density of 1 and 4 mA/cm^2, respectively, and their interface state densities were determined to be 3.68×10^{11} cm^{-2}-eV^{-1} and 6.52×10^{11} cm^{-2}-eV^{-1}, respectively. The result clearly demonstrates at least twofold reduction in the interface state density could be achieved via the anodic oxidation technique. Fig. 3 depicts the different current ratios (photocurrent-to-dark current) measured for detectors passivated with oxides prepared using anodic oxidation and photo-CVD methods. Notice that a stable anodic oxide effectively passivated the SiGe surface which ultimately rendered the device with more than 10-times enhancement in current ratio compared to the one capped with photo-CVD oxide.

CONCLUSIONS

In summary, we have successfully demonstrated the functionality of SiGe-based infrared photodectors being successfully enhanced via the anodic oxidation method; namely, the current ratio was boosted by more than tenfold compared to that of the device capped with photo-CVD oxide. Further details on the SiGe film surface characterizations and photodetectors functional measurements will be reported during the upcoming SSDM 2007 conference.

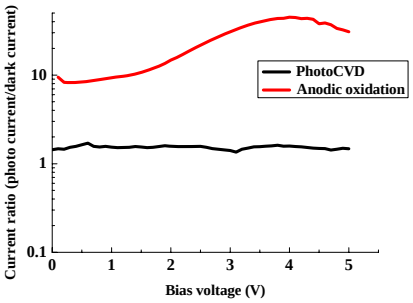

FIG. 3. The comparison of different current ratios (photocurrent-to-dark current) measured for devices passivated with oxides prepared using anodic oxidation and photo-CVD techniques.

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