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Electrical characterization and deep-level transient spectroscopy of $Ge_{0.873}Si_{0.104}Sn_{0.023}$ photodiode grown on Ge platform by ultra-high vacuum chemical vapor deposition

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ABSTRACT

Electrical characteristics and deep-level transient spectroscopy of a $Ge_{0.873}Si_{0.104}Sn_{0.023}$ photodiode grown by ultra-high vacuum chemical vapor deposition on a p++ Ge platform are investigated. The photodiode shows good rectifying I-V characteristics, and the dark current exhibits an activation energy of E_{dc} = 0.43 eV at high temperature while the reverse bias leakage current in the film is low but increases with temperature. Capacitance-voltage measurements show the diode has a built-in potential of 0.37 V at 300 K; the depth profile obtained from capacitance-voltage measurements is in agreement with secondary ion mass spectrometry analysis reported previously. Deep level transient spectroscopy shows two electron traps at ~100 K and at ~165 K with energy levels at ~0.09 eV and ~0.36 eV from the conduction band, respectively; and at least one hole trap at ~275 K with energy level at ~0.61 eV from the valence band (~0.33 eV from the conduction band) existing in the device.

1. Introduction

Interest in next generation devices that integrate photonic and electronic functionality is focused on extending the capability of existing group IV material systems while maintaining compatibility with existing processing methods and procedures. One such class of materials which has been recently developed, $Ge_{1-x-y}Si_xSn_y$ ternary alloys, is being investigated for integrated Si photonics, solar cell materials, telecommunication applications, and for IR photodetectors [1]. The Ge-Si-Sn alloys could offer opportunities to decouple the band gap energies and lattice constants over a wide range of values, potentially yielding direct and indirect character that can be coupled with a variety of different substrates dependent on composition [2]. These alloys show great potential for strain engineering or as compliant buffer layers since their band gap energy and lattice parameter can be tuned independently [3,4]. In addition, for sufficient levels of Sn incorporation, the fundamental optical band gap undergoes a crossover from indirect to direct transition [5–7]. Strain within the film also strongly influences the concentration of Sn required for this transition from indirect to direct transition [4]. On the other hand, since Sn has low solubility in Ge, binary Ge-Sn is thermally unstable especially for large Sn concentrations upon the thermal treatment. Experimental studies and theoretical calculations show that the ternary alloy $Ge_{1-x-y}Si_xSn_y$ is far more stable than $Ge_{1-y}Sn_y$ when both have the same Sn concentration [2]. Therefore, $Ge_{1-x-y}Si_xSn_y$ ternary alloys could enhance stability of Sn-based materials.

Synthesis of $Ge_{1-x-y}Si_xSn_y$ alloys was first demonstrated via a hot wall ultra-high vacuum chemical vapor deposition (UHV-CVD) process using deuterated stanane (SnD_4) and SiH_3-GeH_3 precursors [8]. Low growth temperatures (T < 350 °C) are required to stabilize the substitutional Sn in the SiGe lattice because of the large disparity in atomic size. These deposition processes have subsequently been improved and extended to include the use of higher order group-IV hydride precursors such as Ge_3H_8, Si_3H_8, Ge_4H_{10}, and Si_4H_{10} [9]. Alternative growth processes have also been developed to synthesize $Ge_{1-x-y}Si_xSn_y$ alloys including molecular beam epitaxy [10] and ion implantation of Sn into a SiGe matrix [11]. The optical properties of $Ge_{1-x-y}Si_xSn_y$ alloys showing direct bandgap emissions have been reported [12–14]. GeSiSn-based photodiode devices such as photodetectors, photovoltaic devices have been fabricated [2,3,15,16]. However, little data on the defects in these devices has been reported, although a few studies of electrical traps in GeSn have been published [17–19]. In the present work, we

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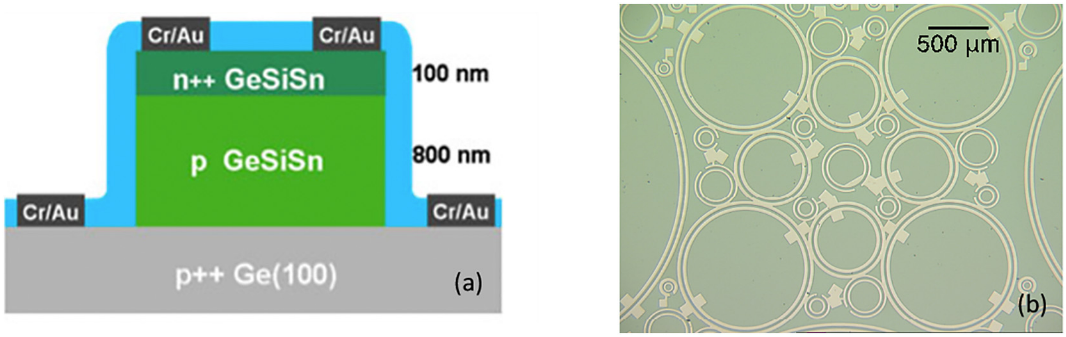

Fig. 1. (a) Schematic drawing of the GeSiSn photodiode grown on p+ + Ge(100), with 900-nm total epilated thickness; the n+ + layer was phosphorus doped at $1 \times 10^{19}\ cm^{-3}$, the p-layer by boron at $1 \times 10^{17}\ cm^{-3}$ and p+ + Ge substrate by gallium at $6 \times 10^{17}\ cm^{-3}$. (b) Top view of the devices. Different mesa structures ranging from 100 to 3000 µm in diameter can be seen.

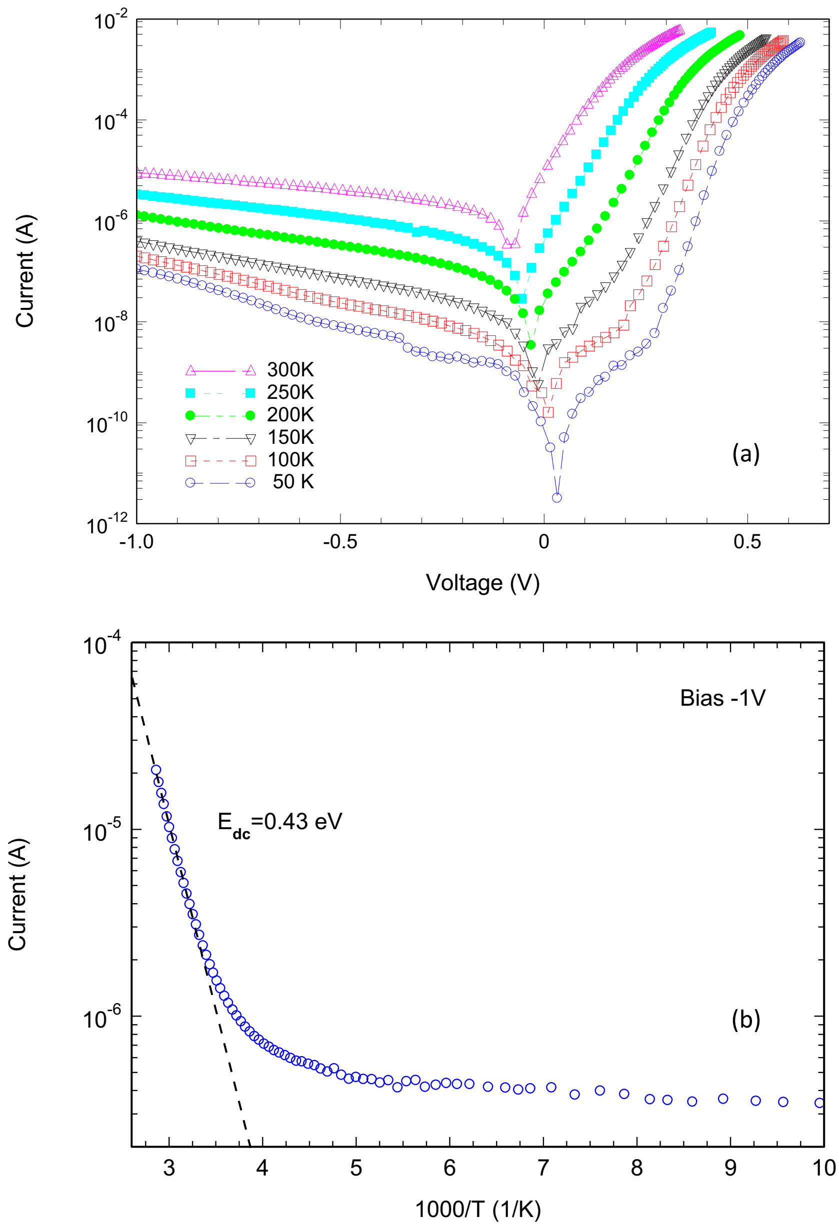

Fig. 2. (a) Temperature-dependent I-V characteristics of $Ge_{0.873}Si_{0.104}Sn_{0.023}$ photodiode with 290 µm diameter (b) Arrhenius plot of the dark current vs 1000/T under −1 V bias. Note that the smallest currents are not at zero bias but deviate from −0.08 V at 350 K to +0.03 V at 50 K, probably due to some thermal inequilibrium of the device during the measurements.