Molecular Beam Epitaxy Growth of Highly Tensile Strained GeSnC alloys up to 4% Sn and 3% C

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ABSTRACT.

Ge has a nearly direct bandgap because the direct r valley (k = 0 in momentum space) is only 140 meV above the indirect L valley. Tensile strain (>2%) and alloying ($Ge_{1-x}Sn_x$ or $Ge_{1-y}C_y$) are the two most common approaches to make Ge-based direct bandgap materials[1]. Although $Ge_{1-x}Sn_x$ becomes a direct bandgap material with x>10%, strained growth on Ge or GaAs adds undesirable compressive strain[2]. Worse, the very small electron effective mass ($m_e^* \approx 0.02m_0$) loses the direct bandgap when confined in a quantum well (QW) or dot[3].

Our group has previously demonstrated that $Ge_{1-y}C_y$ with y ≈ 1% has a direct bandgap, and reported GeC using a special precursor (4GeMe) as a C source in molecular beam epitaxy (MBE), with no defects detected in transmission electron microscopy (TEM)[4,5]. In this work, we instead grew $Ge_{1-x-y}Sn_xC_y$ using a simpler C precursor. GeSnC adds additional control in epitaxial growth: Sn and C partially compensate local strain and distortion of the host Ge bonds. Ab-initio calculations predict that C-Sn-C bonding would be energetically favorable over C-C bonds in the Ge lattice. This is likely to increase both C and Sn substitutional incorporation and provides a more stable material, similar to InGaAs:N[6]. We saw no evidence of Sn segregation as surface droplets, nor C incorporation as undesirable C-C or C=C bonded nano-clusters. Therefore, adding Sn might reduce the carbon clustering at the surface which would be a great achievement compare with past growths by other groups. As an added benefit, GeC offers a larger electron effective mass (m_{eff}), which would preserve the direct bandgap in GeSnC even when confined in a QW.

Tensile strained $Ge_xSn_yC_{1-x-y}$ was grown on GaAs (004) substrate in hybrid MBE using thermal Ge, Sn sources and commercial carbon tetrabromide (CBr_4) as the carbon source. We believe C-C pairs are likely defects in the carbon containing alloys, so we also used hydrogen to preferentially remove sp2 carbon, as is done in growth of epitaxial diamond. High resolution x-ray diffraction (HRXRD) reveals good crystallinity in the epi-layer with maximum 3% of substitutional carbon and 4% tin. Raman observation of the C local mode at 530 cm^{-1} confirms substitutional incorporation into the crystal. Atomic Force Microscopy (AFM) shows mostly flat surfaces. Unlike most other carbon sources, no sp2 (graphitic) or amorphous carbon bonds were detected in Raman spectroscopy from 1200-1600 cm^{-1} (not shown). The successful incorporation of C into Ge substitutionally, without cluster carbon, is a major step toward efficient Group IV

lasers for silicon photonics. We have also observed emissions in 0.50-0.60 eV range both from bulk and multiple quantum well (MQW) GeSnC samples. These peaks could be from different atomic arrangements, from defects, or from non-uniform QW compositions. The detailed origins of the emission spectrum are currently under investigation and will be reported at the conference.

Reference

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Extended Abstract

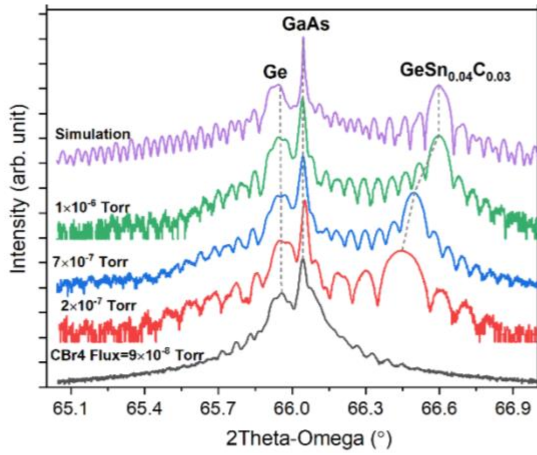

Figure 1. HRXRD ω-2θ scans about GaAs (004) Bragg reflection as a function of CBr4 fluxes

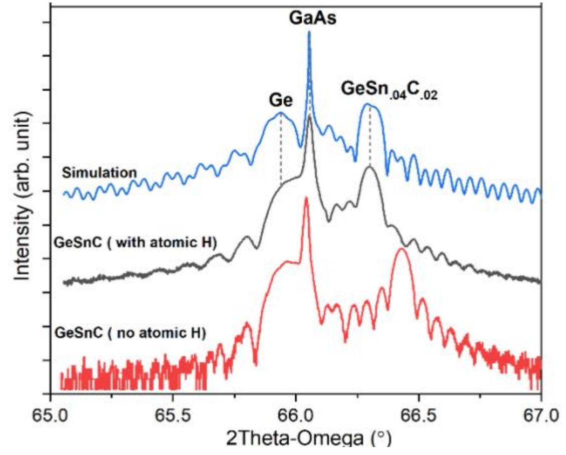

Figure 2. HRXRD ω-2θ scans about GaAs (004) Bragg reflection with and without atomic H

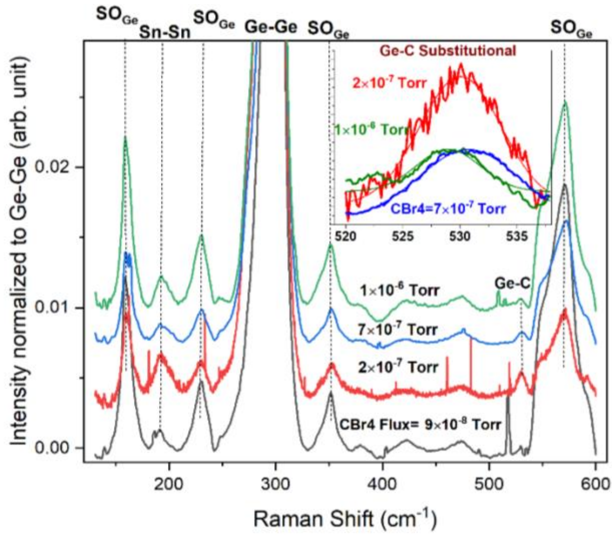

Figure 3. Raman spectra of GeSnC as a function of CBr4 fluxes and substitutional Ge-C at 530 cm^{-1} (inset)

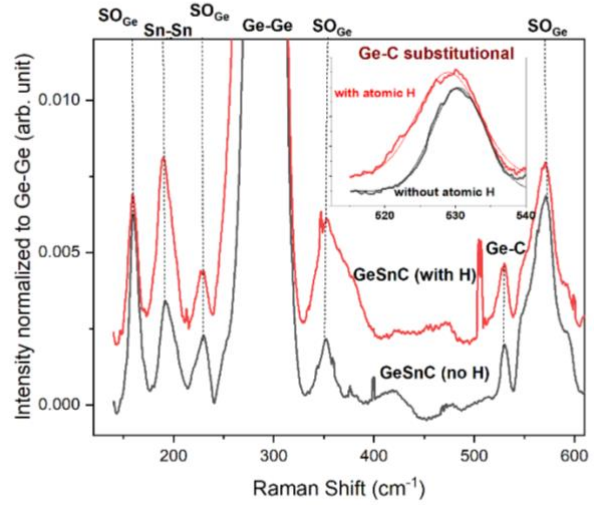

Figure 4. Raman spectra of GeSnC with/ without atomic H and substitutional Ge-C *at 530 cm^{-}* (inset*)*

RMS Roughness ~ **1 nm**

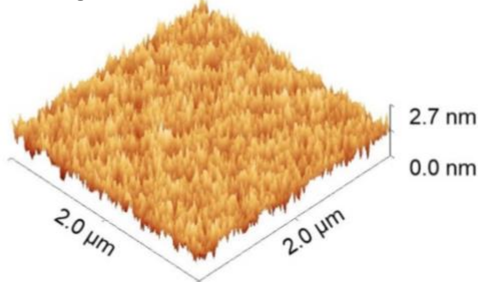

Figure 5. AFM image of GeSnC surface without atomic H

RMS Roughness ~ **3 nm**

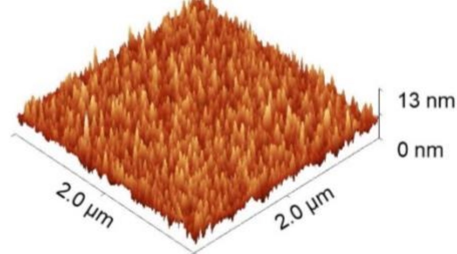

Figure 5. AFM image of GeSnC surface with atomic H