$Ge_{1-x}Sn_x$ alloys synthesized by ion-implantation: from epitaxial thin films to crystalline nanostructures

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Abstract

Group IV semiconductor alloys have drawn substantial attention for their potential applications in optoelectronic devices capable of integration with the existing silicon-based IC circuitry. Monocrystalline $Ge_{1-x}Sn_x$ alloys are promising for electronic and optical applications in virtue of their high carrier mobility and possibility of direct bandgap transition [1,2].

In this contribution we present the monocrystalline $Ge_{1-x}Sn_x$ thin film and nanostructure synthesized by ion implantation, by which the low solubility of Sn in Ge can be overcome. Sn was implanted into commercial Ge wafers at room temperature. After implantation, cross-sectional transmission electron microscopy (TEM) image reveals a 70 nm thick Sn-doped porous structure on 80 nm thick Sn-doped amorphous Ge layer. The implantation induced amorphized layer has been recrystallized after ultrashort thermal process. By nanosecond pulsed laser melting (PLM), high quality monocrystalline $Ge_{1-x}Sn_x$ thin films were obtained through a bottom-up liquid phase epitaxial process. On the other hand, solid phase recrystallization induced by millisecond flash lamp annealing (FLA) results in crystalline $Ge_{1-x}Sn_x$ porous nanostructures. Depending on the FLA condition, the structure can be polycrystalline or monocrystalline.

Field emission scanning electron microscopy was applied to measure the surface morphology. High resolution transmission electron microscopy and Rutherford backscattering and channeling analysis confirmed the monocrystalline structure of the $Ge_{1-x}Sn_x$ layer. The crystallinity and the lattice expansion due to Sn doping were determined by X-ray diffraction and micro-Raman spectroscopy. Our investigation provides an efficient, IC-compatible technique to prepare high quality monocrystalline $Ge_{1-x}Sn_x$ alloys.

References

[1] J. Kouvetakis *et al.*, Ann. Rev. Mater. Res., (2006) 36, 497.
[2] J. Mathews, *et al.*, Appl. Phys. Lett., (2010) 97, 221912.

Figures

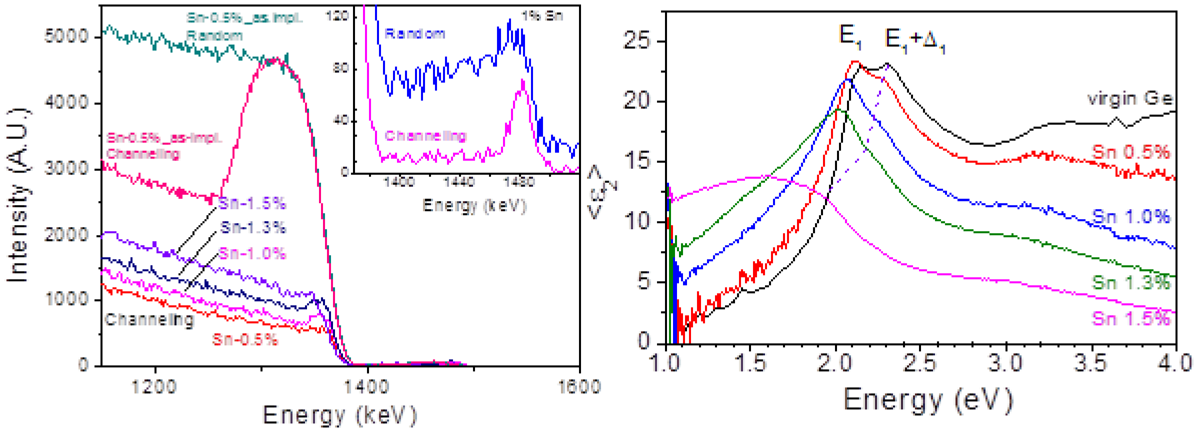

Fig. 1 (Left) <001> Random and channeled RBS spectra of as-implanted $Ge_{1-x}Sn_x$ with 0.5% Sn, and PLM treated $Ge_{1-x}Sn_x$ samples with Sn concentrations ranging from 0.5% to 1.5%. The inset shows the magnification of the random and channelling Sn signals from PLM treated samples with 1.0% Sn. (Right) Imaginary parts (ε_2) of the complex dielectric function of PLM treated $Ge_{1-x}Sn_x$ alloys with different Sn concentrations determined by ellipsometry. The peaks E_1 and $E_1+\Delta_1$ marked in the figure correspond to transitions between the top two valence band and the lowest conduction band along the <111> direction

in the Brillouin zone. The clear redshifts of the E_1 and $E_1+\Delta_1$ with respect to increasing Sn concentration provides a direct evidence of the bandgap shrinkage as a consequence of the Sn-doping.

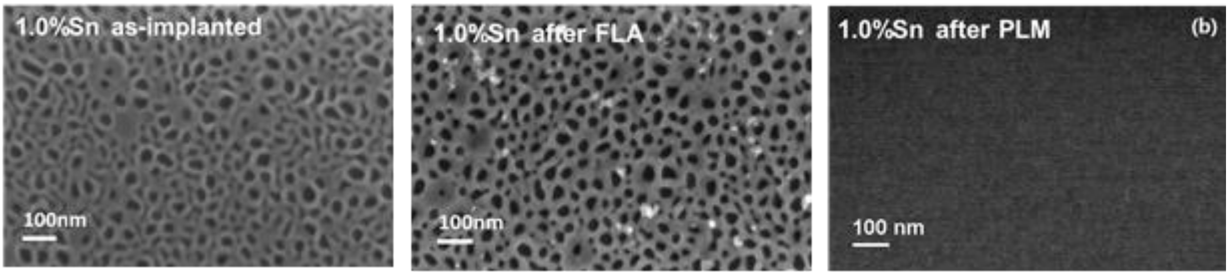

Fig. 2 SEM topography of Sn-implanted Ge. (left) as-implanted, (middle) after FLA, and (right) after PLM.

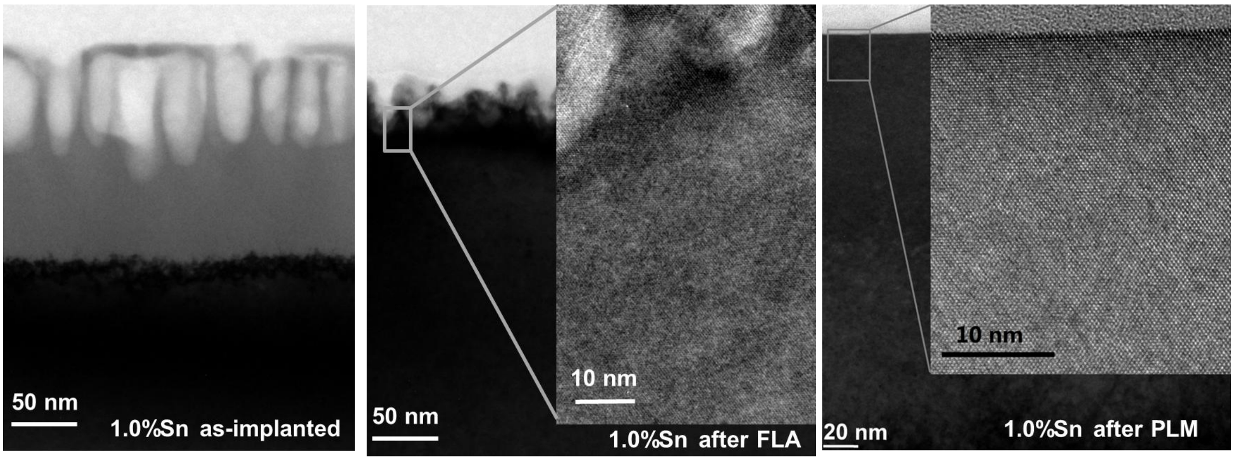

Fig. 3 Cross-sectional bright-field TEM micrograph and high-resolution TEM image (inset) of Sn-implanted Ge. (left) as-implanted, (middle) after FLA, and (right) after PLM.