

Si-Ge-Sn based compound semiconductors for photonic applications.

Radek Roucka, Andrew Clark, Nam Pham

Translucent Inc., 952 Commercial St., Palo Alto, CA 94303

Phone: (650) 213-9311 Fax: (650) 213-9511 Email: info@translucentinc.com

Introduction

III-V compounds with their high mobilities and direct bandgaps have driven the development of many different device architectures for photonic and electronic applications. Integration of these III-V devices with silicon is now a major focus for the industry, with a variety of approaches being developed, ranging from direct epitaxial growth to wafer bonding. With each method there are technical challenges and costs issues to overcome. Nowadays III-V alloys are readily grown on Ge substrates. At Translucent the growth of group IV compound semiconductors on Ge has also been established. The Si-Ge-Sn materials system can add to the functionality of the devices but importantly it can also be used to integrate III-V materials with a silicon substrate. The details of the growth of these materials and their use as a virtual Ge substrate technology are given below. The process at Translucent is based on CVD process utilizing deuterated stannane SnD_4 and digermane Ge_2H_6 at low temperatures (300-450°C). This process is preferred since it also allows growth of alloys containing variable amount of Sn and with addition of trisilane Si_3H_8 one can obtain ternary Si-Ge-Sn alloys. These are of high interest for their ability to vary the bandgap while keeping the lattice constant fixed. We would like to note that all used precursors are commercially available and their implementation in the industrial process is straightforward.

Si-Ge-Sn alloys

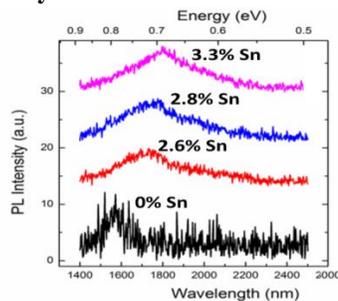


Figure 1: Photoluminescence spectra from Ge-Sn films on Si with Sn content up to 3.3%.

We have started with the alloys containing no Si. Ge-Sn layers with Sn content up to 4% have been synthesized on Si wafers. The layers exhibited good crystallinity and high temperature stability up to 700°C. The material is relaxed for all composition. To demonstrate the variable bandgap, PL signal from several alloys with increasing Sn content was collected. The data is shown in the Figure 1. The peak of the emission spectra shifts to the higher wavelengths (lower E_g) with increasing Sn content. At 3.3 % Sn the emission peak maximum is in the range of 1850 nm (0.72 eV) – far beyond the emission spectra of Ge (bottom curve). This range overlaps with the bandgaps of high In containing InGaAs alloys and the achieved values show a promising potential for future applications in the mid and far infrared light emission and detection.

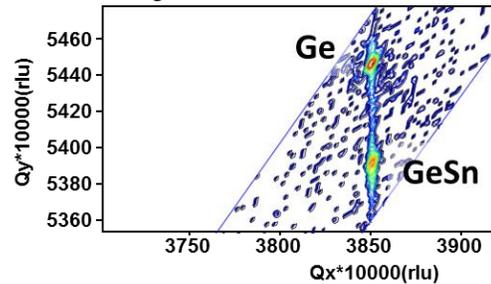


Figure 2: XRD reciprocal space map around the (224) peaks of Ge substrate and fully strained 300 nm thick GeSn layer with 5% Sn.

Ge-Sn has been also grown directly on bulk Ge substrates. In this case, the growth results in fully strained layers. The Figure 2 shows an XRD reciprocal lattice map of a 300 nm thick GeSn layer with 5 % Sn grown on bulk Ge. The map was collected around the (224) diffraction peak of Ge and we can clearly see that the Ge-Sn alloy is fully strained (has the same in-plane lattice parameter) to the underlying Ge. We have found that upon annealing at 650 °C the layer partially relaxes.

With addition of Si to the Ge-Sn alloys we can fix the lattice parameter of the alloy, while we still vary the bandgap. For the ternaries, however, the range is also expanded to the higher E_g values 0.6 - 1.4 eV. Such

range potentially covers the highly desirable alloys with 1.0 eV gaps for multijunction solar cell devices. Those combine several junctions typically made of III-V compounds with lattice matching conditions.

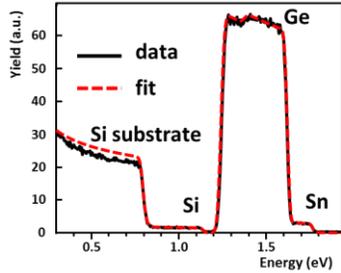


Figure 3: RBS spectrum and model fit of Si-Ge-Sn layer containing 2% Sn, 11% Si and 87% Ge with 600 nm thickness grown on Si substrate.

Figure 3 shows an RBS spectrum collected from a layer of 600 nm thick Si-Ge-Sn alloy grown on Si substrate. The positions of the edges in the spectrum correspond to the different elements (Si, Ge, Sn) and their height is related to the atomic concentration. This particular sample contains 2% Sn, 11% Si and 87% Ge. The XRD spectrum shown in Figure 4 shows data obtained from the same sample. The spectrum is overlaid with the scan from pure Ge layer grown on Si to demonstrate the lattice matching condition.

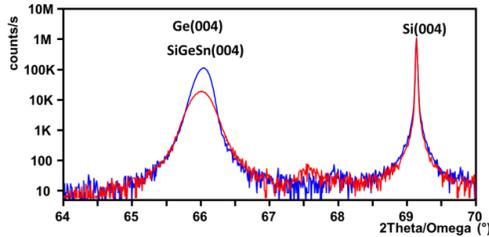


Figure 4: XRD (004) scan of the SiGeSn layer showing a case of alloy lattice matched to Ge (bottom curve).

Since our goal is to develop materials for the photovoltaic industry, we have successfully grown Ge-Sn and SiGeSn on both bulk Ge and GaAs substrates to demonstrate the direct integration. On both substrates the epitaxial layer exhibit high crystalline quality measured by the FWHM of the (004) XRD peak maxima (54 arcsec for Si-Ge-Sn vs 38 arcsec for bulk Ge), see Figure 5. The surface roughness of the films was in the range of 0.2 nm – comparable to the bulk Ge wafer surface.

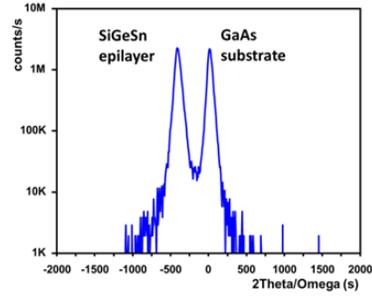


Figure 5: XRD plot showing SiGeSn epilayer grown on GaAs substrate.

With respect to the subsequent deposition of MOCVD grown III-V compounds, the thermal stability of the Ge-Sn was tested and the materials were found to be stable at temperatures up to 700°C. The Ge-Sn alloys with Sn content up to 3% can withstand the entire growth cycle required to deposit 6 microns thick InGaAs layer. Another example of III-V photonic device application is shown in the Figure 6, where we show a reflectivity measured from GaAs/AlAs DBR structure designed for 850 and 1300 nm and grown on Ge-Sn template Si.

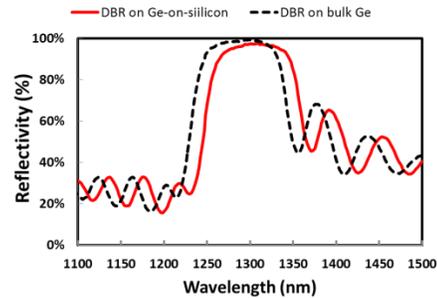


Figure 6: Reflectivity curve of 1300 nm DBR structure grown on bulk Ge and Ge/Si template.

Conclusion

We have shown that the Si-Ge-Sn compound semiconductors provide a viable route for integration of III-V compounds with Si and at the same time these materials provide an alternative to achieve broad range of bandgap values while satisfying the fixed lattice constant conditions.

Keywords:

Si-Ge-Sn alloys, solar cell, III-V integration