2μm Electro-Absorption Optical Modulation using Strained Germanium-Tin on Silicon

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1. Introduction

GeSn alloys have been recently considered as a new class of group-IV semiconductors for silicon photonics [1]. Introducing Sn into Ge can effectively engineer the bandgap, allowing for extending the absorption edges to mid-infrared (MIR) region. This unique property has led to the development of GeSn photodetectors with extended optical responses [2-4]. In addition to photodetectors, another important photonic active device is optical modulators. Here, we present an investigation of optical modulation in GeSn alloys based on the Franz-Keldysh (FK) effect for 2 μm band applications. We fabricated normal-incident GeSn optical modulators and experimentally demonstrate optical modulation at 2 μm wavelengths.

2. Experiments

The samples were grown on double-side polished Si (001) substrates using molecular beam epitaxy. The structure consists of (a) a 120-nm-thick Ge virtual substrate, (b) a 250-nm-thick p-type Ge, (c) a 300-nm-thick $Ge_{0.96}Sn_{0.04}$ layer, and (4) a 100-nm-thickn-type Ge layer. Because of the pseudomorphic growth condition, the $Ge_{0.96}Sn_{0.04}$ is subjected to a 0.57% compressive strain. The samples were then fabricated into normal-incident devices using standard CMOS-compatible processes with a circular mesa of 500 μm. Light is normally incident on the surface of the GeSn optical modulator with different swing voltages, and the transmitted light is collected and analyzed using an InSb photodetector with a lock-in technique to enhance the signal to noise ratio. A schematic diagram of the device is depicted in the inset of Fig. 1.

3. Results and Discussion

Figure 2 shows the measured transmittance difference (ΔT) spectra with different swing voltages. The results show clear oscillations induced by electric fields well below Ge's direct absorption edge (~1550 nm), provide evidences for the FK effect in GeSn. In addition, the compressive strain splits the heavy-hole (HH) and light-hole (LH) bands, so the direct-absorption edge is defined by the HH→cΓ interband transition. The introduction of 4% Sn reduces the direct bandgap from 0.8 eV (1550 nm) to 0.65 eV (1980 nm). As a result, the transmittance significantly decreases below the absorption edge as the swing voltage increases because of the increased absorption coefficient induced by the electric fields, demonstrating electro-absorption optical modulation at 2 μm wavelengths.

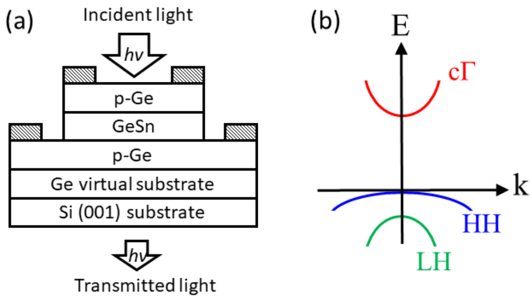

Figure 1. Schematics of the GeSn optical modulator. (b) Schematic band structure of pseudomorphic GeSn on Ge.

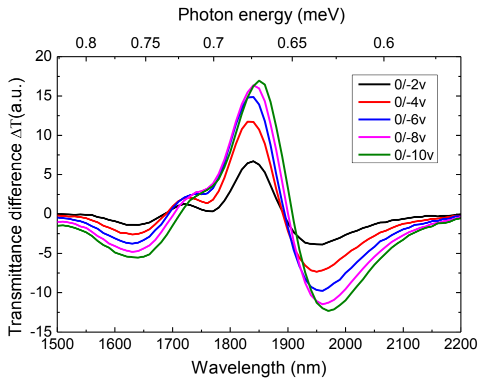

Figure 2. Measured transmitted spectra of the GeSn optical modulator with different swing voltages.

3. Conclusions

We have demonstrated clear Franz-Keldysh optical modulators on silicon capable of operation at 2 μm wavelengths. These results represent an important step for the development of mid-infrared GeSn-based optical modulators on silicon.

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