Electrical Properties of the Germanium-on-Silicon Interface

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Abstract and Introduction:

Germanium-on-silicon (Ge/Si) photodetectors show promise for use in photonics applications due to their high bandwidth, low cost, and compatibility with silicon-based electronics. The performance of such devices is limited by defects at the interface between the two materials. Si and Ge crystals have a 4% lattice mismatch, which results in traps, or energy states between the valence and conduction bands, which carriers can inhabit. Information about how these traps affect performance is useful when designing devices.

This project tested Ge/Si photodetectors in order to characterize their electrical properties. Two separate types of measurements were taken. The open-circuit voltage (V_{oc}) of the detectors was measured as a function of temperature to determine the activation energy of the transport mechanism across the detector's *p-n* junction, and the transient decay of an electrical signal under open and short circuit conditions was measured in order to determine the minority carrier lifetime in the device.

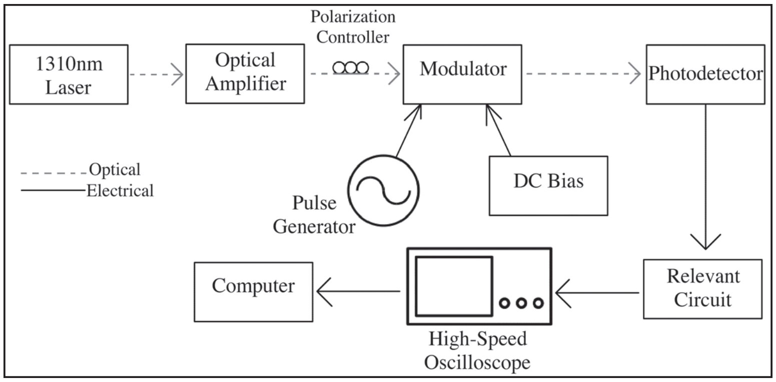

Figure 1: Block diagram of experimental setup used for transient measurements.

Device Specifications:

This work tested two different devices. Device A was a Ge waveguide detector with a negative (*n*)-doped Ge layer, an intrinsic Ge layer, and a positive (*p*)-doped Si layer. Device B was a top-illuminated uni-traveling carrier (UTC) photodetector with a *p*-doped Ge layer, an intrinsic Si layer, and an *n*-doped Si layer.

Experimental Procedure:

Open-circuit voltage measurements were performed on devices A and B. Light from a 1310 nm laser was directed by a lensed fiber to the photosensitive region, which was reached via a Si waveguide for Device A and top-down illumination for Device B. The devices were placed on a stage that allowed device temperature to be controlled, and measurements were taken at 5°C increments from 15-65°C. At each temperature, the probe applied a range of voltages to the device and the current at each voltage was recorded. The results were analyzed in order to find V_{oc}, the voltage corresponding to a current of 0A.

Transient measurements were performed on Device B using the experimental set-up in Figure 1. The pulse generator sent a square-wave into the modulator in order to change the light emitted by the 1310 nm laser into an optical pulse of the same shape, and traces of the produced electrical signal were recorded. The "relevant circuit" indicated in Figure 1 is the circuit used to produce either short or open circuit conditions. To create short-circuit conditions, the device was attached directly to a digital communication analyzer (DCA), which provided a 50Ω parallel resistance.

Because the measured current was small, this only resulted in a 12.5 mV voltage drop across the device. To create open-circuit conditions and to amplify the signal to a measureable level, an op-amp circuit with a 2.2 MΩ input impedance was used. To ensure the measured decay was due to carrier recombination, an LCR meter was used to measure the RC limit of the device, and the fall time of the experimental setup was measured with the DCA.

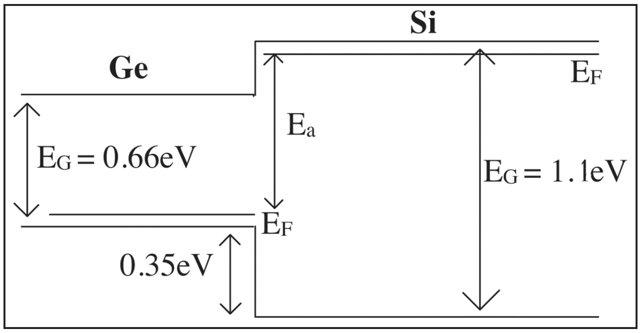

Figure 2: Flat band diagram of p-n junction showing mechanism for Device B.

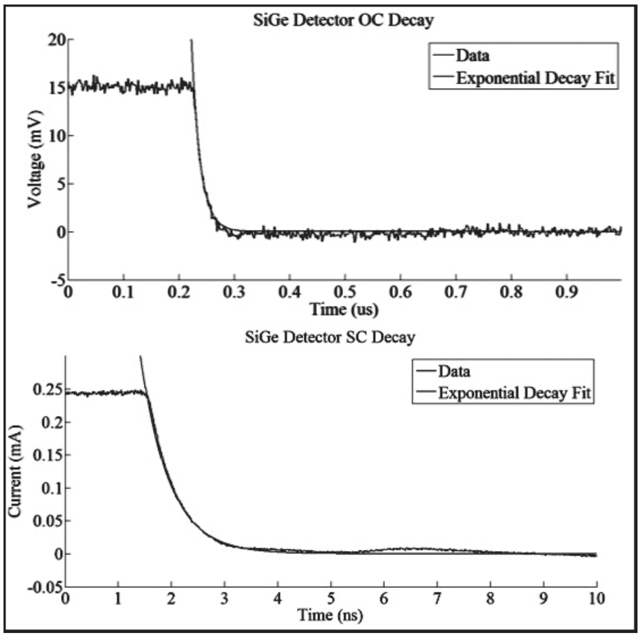

Figure 3: Experimental data and theoretical fit for open- and short-circuit transient measurements with DC offset.

Result and Conclusions:

The V_{oc} measurements were fit to Equation 1:

$$qV_{OC} = E_a - mT \quad [1]$$

to determine E_a, the activation energy of the transport mechanism across the device's *p-n* junction, as seen in Figure 2. This value was calculated to be 0.09 eV less than the ideal value for Device B and 0.29 eV less than the ideal value for Device A. These lowered activation energies demonstrate that traps present in the material contribute a portion of the device's total current.

The traces from the transient measurements were fit to exponential decays as seen in Figure 3. The open-circuit measurement yielded a decay constant (τ_V) of 15.2 ± 1.7 ns and the short-circuit measurement yielded a decay constant (τ_J) of 0.543 ± 0.008 ns. Mathematical methods presented in [2] were used to relate τ_V and τ_J to the minority carrier lifetime, τ.

The analysis yielded no self-consistent solution, likely due to assumptions made in the mathematical model that did not apply to these devices. Nonetheless, trends in values of τ_V, τ_J, and τ presented in [3] imply a τ value in the 10-100 ns range.

Reported values for Ge grown on lattice matched substrates are between 1 and 10 μs, demonstrating that defects reduce the minority carrier lifetime in Si/Ge devices.

Future Work:

Future work could further characterize the types of traps present in the devices. Defect density in the material could be measured directly through etch pit studies or with the use of transmission electron microscopy (TEM). Also, simulations could be conducted using the experimental data to determine if a single type, capture rate and recombination velocity describe the traps. Measurements of the temperature dependence of the minority carrier lifetime could yield further information about the types of traps present.

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References:

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