Abs. 1386, 206th Meeting, © 2004 The Electrochemical Society, Inc.

Photoresponse Study of Ge QDIPs for Mid-Infrared Wavelength

Song Tong, Joo-Young Lee, Fei Liu, Hyung-Jun Kim, and K. L. Wang
Device Research Laboratory, Department of Electrical Engineering, University of California at Los Angeles, Los Angeles, California 90095-1594

In the recent years, quantum dots (QDs) such as InGaAs (1) and Ge (2) dots have been successfully grown by self-assembling methods. QDs are 3-dimensional confinement objects and thus can be used for the detection of normal incidence illumination. Quantum dot infrared photodetectors (QDIPs) have attracted a great deal of interest (3,4). However, much of the work was done on III-V QDs. Here we report our results obtained from Ge QDIPs in 3-5 μm at normal incidence.

The device samples are grown with a P-I-P structure, with p-type doped Ge dots in the intrinsic Si region, sandwiched by two p^+ regions as contact layers. Highly p-type doped Si (100) wafers with resistivity of 0.01 Ω·cm were used as substrates. The structure includes a 200 nm p^+ Si buffer layer, 20 periods of Ge quantum dots and undoped Si spacers, and another 200 nm p^+ Si contact layer. The nominal thickness of each Ge layer was 1.4 nm and was doped at a level of 1×10^{18} cm^{-3}, and each spacer layer is 20 nm. Identical structures were grown on high resistivity double-side-polished substrate for FTIR analysis. The device samples were processed into mesa diodes with conventional methods. The mesa size is 250x250 μm^2. Photoresponse spectra were taken at normal incident geometry with a glow bar operating at 70 W, a 34-cm grating monochromator and a lock-in amplifier.

Figure 1 shows the FTIR results for samples grown at three temperatures, 540, 650 and 700 °C. A peak corresponding to the carrier absorption in Ge QDs appeared in the 3-5 μm range. This peak shifts to longer wavelength with increasing the growth temperature. The absorption coefficient obtained from this result is about 6×10^3 cm^{-1}.

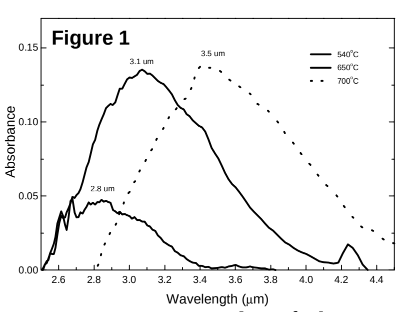

Fig. 1, FTIR results of three samples grown at different temperatures.

Figure 2 shows the I-V curves at dark condition for the sample grown at 540 °C (sample A). A fast current decrease with decreasing temperature was observed. This is due to the thermal activation effect of the holes confined in Ge QDs. For the voltage dependence, two regions of difference slope were observed, which is believed to be due to the different electrical field distribution for different biases.

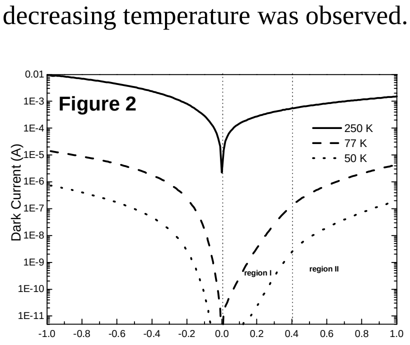

Fig. 2, I-V curves of sample A at different temperatures.

Figure 3 shows the photoresponse curves for sample A at different temperatures. A peak at around 2.9 μm was observed. This agrees well with the 3.1 μm absorption peak given by FTIR measurement. It was found that with increasing temperature, the response intensity increased. This is mainly due to that the ionization probability of dopants will increase at higher temperature. The dips appear in the curve are due to the interference of the epi-layer as well as the absorption in the atmosphere. Figure 3 also shows the response spectrum of sample B grown at 700 °C measured at 77K and that of sample A as a reference. Sample B has a response peak at 3.6 μm, showing that by controlling the temperature, the photoresponse range can be conveniently tuned.

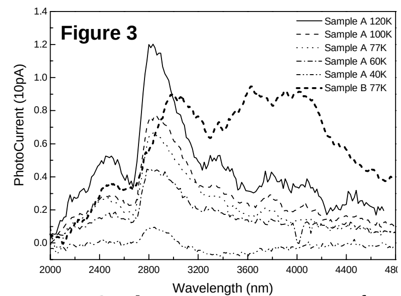

Fig. 3, Photoresponse spectra of sample A and B.

Figure 4 shows the photocurrent dependent on the applied voltage for sample A. Two wavelengths were chosen, 2.84 and 3.4 μm. First, it can be seen that there is a photovoltaic effect from the device; i.e., at no bias, the photocurrent is non-zero. This is due to the asymmetry of the band structure since the wetting layers introduce a shallower potential than the dots (5). Second, the photoresponse intensity increases with bias. Several regions were discovered, and this should due to the field induced filling of holes into the dots.

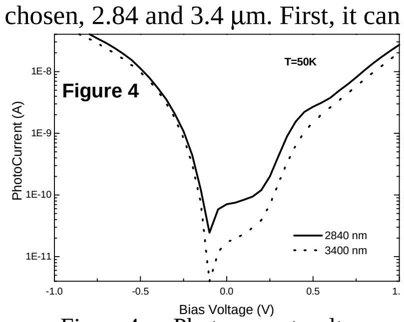

Fig. 4, Photocurrent-voltage dependent at 2.84 and 3.4 μm.

In conclusion, PIP photodiodes were fabricated from Ge QDs grown on Si substrate. The response at normal incidence is in 3-5 μm range, and can be tuned by the growth temperature. Such photodetectors have the potential to be integrated with Si IC technology.

ACKNOWLEDGMENTS

Financial support by MURI under the Centroid project and phonon program is gratefully acknowledged.

REFERENCES

1. D. Leonard, M. Krishnamurthy, C. M. Reaves, S. P. Denbaars, and P. M. Petroff, Appl. Phys. Lett. **63,** 3203(1993).
2. H. Sunamura, S. Fukatsu, N. Usami et al., J. of Crystal Growth, **157**, 265(1995).
3. V. Ryzhii, Semiconductor Science & Technology **11,** 759(1996).
4. H. C. Liu, M. Gao, J. McCaffrey, Z. R. Wasilewski, and S. Fafard, Appl. Phys. Lett. **78**, 79(2001).
5. D. Pan, E. Towe, and S. Kennerly, Appl. Phys. Lett. **76,** 3301(2000).