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Carrier and Phonon Transport in Ge/Si Quantum Dot Superlattices

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Quantum dot superlattices (QDS) attract significant attention of the device research community due to their proposed applications in photodetectors, photovoltaics, and thermoelectric devices [1-2]. In all envisioned applications it is critical to maintain relatively high carrier mobility and/or conductivity. Indeed, the photogenerated carriers in quantum dot photodetectors or photovoltaic cells should be able to travel to the metal contacts before they recombine. Good electric conductivity is also important for thermoelectric materials where the figure of merit Z at given temperature T is defined as $ZT=\alpha^2\sigma T/K$ (α is Seebeck coefficient, σ is electrical conductivity, K is thermal conductivity). The requirements for thermal conductivity K depend on the specific application: it is desirable to have low K for thermoelectric elements, while electronic circuits and optoelectronic devices need high K for better heat removal. In this report I will review recent results of Hall mobility and thermal conductivity measurements in doped and undoped Ge_xSi_{1-x}/Si quantum dot superlattices (x=0.3; 0.5) carried out in the Nano-Device Laboratory (NDL). Theoretical interpretation and modeling data will also be presented.

Carrier transport in QDS can manifest both hopping and conduction band transport features. The hopping transport regime is characterized by much lower mobility than the band conduction transport, and by different temperature dependence. Despite importance for practical applications there have been little work done on carrier transport in QDS [3]. For this study we have used two batches of QDS samples fabricated by two different research groups. The undoped samples with typical Ge content in the dots of 50% have been grown in a Perkin Elmer MBE system (Prof. J.L. Liu group, UCR). The doped samples with typical Ge content in the dots of 30% have been grown in a Riber EVA32 (Prof. Y.H. Xie group, UCLA). All investigated QDS with either 5 or 20 layers of quantum dots have been grown on p-type Si wafers. There were three different positions for δ-doping layer in the doped QDS (wetting layer, quantum dot layer, barrier layer).

From SEM images we estimated that the density of Ge quantum dots is about 3×10^9 cm^{-2} and the average base diameter is 40 nm. The height of 4 nm has been determined from AFM scans. Using Raman spectroscopy data we established that the Ge dot layers were not under very strong strain. This conclusion was based on comparison of Si and Ge peak positions in Ge/Si QDS with those in bulk Si (520.4 cm^{-1}) and Ge (301 cm^{-1}). Raman spectroscopy has been carried out using Renishaw instrument under 488 nm excitation. The spectra of QDS exhibited only small deviation (~ 1 cm^{-1}).

Thermally diffused contacts made of aluminum were formed on top of the superlattices to carry out Hall measurements. The Hall mobility was measured using EGK HEM-2000 system at the room temperature and 77 K. The measurements were conducted in a standard four-terminal scheme to ensure the accuracy. Most of the data points were taken at the magnetic field of 0.37 T.

The average measured in-plane Hall mobility for p-type structures is 140 cm^{2}V^{-1}s^{-1} at 300 K (see Figure 1) and 2.4×10^3 cm^{2}V^{-1}s^{-1} at 77 K. Relatively large values and temperature dependence suggest that in given QDS the carrier transport is likely of the band conduction type rather than hopping type [4]. The TEM and SEM microscopy of the QDS reveal strong size dispersion of the dots and relatively large inter-dot distance. Thus, it is unlikely that extended 3D mini-bands [5] are formed in these particular QDS samples. It is possible that many parallel channels (thought coupled quantum dots, wetting layer or cap layer) are contributing to current conduction.

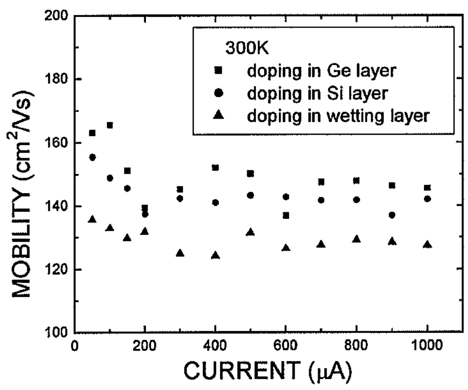

Figure 1. Hall mobility in the doped Ge/Si quantum dot superlattices as a function of the input current at room temperature.

Thermal conductivity of Ge/Si QDS was measured over a wide temperature range (4K – 550K) by the 3-ω method [6], using in-house built experimental setup. In conclusion, the results of the measurements of carrier mobility and thermal conductivity in Ge/Si QDS will be compared with theoretical predictions for QDS.

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References

[1]. A. A. Balandin and O. L. Lazarrenkova, *Appl. Phys. Lett.*, **82**, 415 (2003).
[2]. E. Towe and D. Pan, *IEEE Journal of Selected Topics in Quantum Electronics*, **6**, 408 (2000).
[3]. A. I. Yakimov, C. J. Adkins, R. Boucher, A. V. Dvurechenskii, A. I. Nikiforov, O. P. Pchelyakov, and G. Biskupski, *Phys. Rev. B*, **59**, 12598 (1999).
[4]. Y. Bao, A.A. Balandin, J.L. Liu, J. Liu and Y.H. Xie, *Appl. Phys. Lett.*, **84**, 3355 (2004).
[5]. O.L. Lazarenkova and A.A. Balandin, *Phys. Rev. B*, **66**, 245319 (2002).
[6]. S.M Lee and D.G. Cahill, *J. Appl. Phys.*, **81**, 2590 (1997).