Thermometry and Refrigeration using Quantum Dots

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The two-dimensional electron gas in GaAs/AlGaAs heterostructures has diverse applications at cryogenic temperatures, but is heated by noise in the measurement set up. Our work involves the fabrication of a quantum dot refrigerator which can cool the electron gas to below the ambient lattice temperature[1].

Lithographically defined Ti/Au gates patterned on the surface of a GaAs/AlGaAs heterostructure define three quantum dots (left, right, and top) of radius 150 nm, tunnel-coupled to an enclosed, macroscopic, two-dimensional reservoir of electrons 100μm^2 in area. The QDR uses the discrete energy levels of two quantum dots to cool the central electron reservoir (Fig 1). The third quantum dot (the 'thermometer') probes the temperature of the two dimensional reservoir being cooled (Fig 2, inset).

Our temperature measurement scheme consists of monitoring the charge distribution of the thermometer dot. This dot is open only to the enclosed reservoir whose temperature we want to extract. Changing the energy level of the dot through the Fermi-Dirac energy distribution of the enclosed reservoir results in the occupation probability of the dot being described by the same distribution. This is reflected in the current flowing through an adjoining quantum point contact. Fitting a Fermi-Dirac distribution to the measured current thus yields the temperature of the two-dimensional reservoir (Fig 2). We have demonstrated measuring electronic temperatures in the range 100 mK to 300 mK, with errors as low as 5 mK. The limits of this temperature measurement scheme still have to be explored. Using this scheme, we have also investigated the variation in the electron temperature as a function of the voltages on the top and right plunger gates. This variation is produced because the changing voltages on the plunger gates move the energy level of the entrance dot down through the Fermi level of the source while moving the level of the exit dot up through the Fermi level at the drain, thus changing the energy extracted from the reservoir. Our results agree qualitatively with the model of electron cooling developed by Edwards[2].

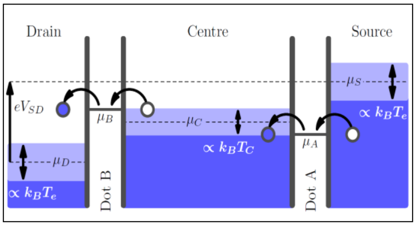

Fig 1: Energy level diagram of a Quantum Dot Refigerator in the cooling regime.

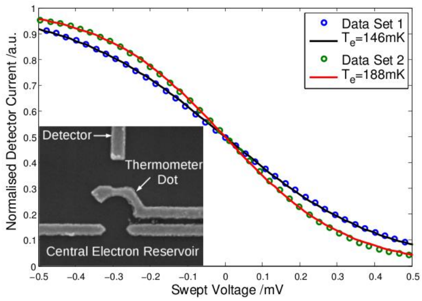

Fig 2: Fitting a Fermi-Dirac function to the detector current of the thermometer dot. Two measurements (for different voltages on the entrance and exit dots) are presented here, with the extracted electron temperatures differing by 40mK. Inset: Scanning Electron Micrograph of a quantum dot and the adjoining quantum point contact.

References

[1] J. R. Prance, C. G. Smith, J. P. Griffiths, S. J. Chorley, D. Anderson, G. A. C. Jones, I. Farrer, and D. A. Ritchie 2009 *Phys. Rev. Lett.* **102** 146602
[2] H. L. Edwards, Q. Niu, G. A. Georgakis, and A. L. de Lozanne 1995 *Phys. Rev. B* **52** 5714