Quantum Transport in Nanoscale MOSFETs

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Quantum computers

As the end of Moore’s Law approaches, the technology of quantum computers offers solutions to the problems of transistor miniaturisation and power dissipation. Quantum computers encode information into states of particles, for example, into the spin of an electron, and could potentially perform unique calculations, such as factorisation and modelling of quantum systems. This thesis involved researching two separate aspects of nanofabrication at The Centre for Quantum Computer Technology (CQCT) at UNSW: aluminium to aluminium contacts and transport properties of nanoscale MOSFETs. Both parts required fabrication, including photolithography, electron beam lithography (EBL) and aluminium evaporation, as well as measurement of custom-made devices within the Centre laboratories.

Aluminium to Aluminium Contacts

Problem description: A layer of native oxide that forms on the surface of aluminium acts as a high resistance barrier between two successively deposited metal layers. This prevents electrical conduction, and requires entire device patterns to be written in one step of EBL. This is time consuming when fabricating a significant number of devices, and the ideal process would be to use EBL to draw the nanoscale top and/or barrier gates and then photolithography for the relatively large connectors.

Solution: To try and achieve reasonable conductance, an initial layer of aluminium was chemically etched using 2.38% TMAH, a known aluminium oxide and aluminium etchant. The etch times were systematically varied, with the second layer of aluminium evaporated immediately after etching to minimise reformation of the oxide. The device used is shown in Fig. 1.

Conclusion: Although resistance values as low as 5Ω were measured after etching thicker layers of metal, ultimately, TMAH was found to be unsuitably aggressive for the thin layers of metal used in typical devices.

Transport Properties of Nanoscale MOSFETs

Background: Transport properties of the n-dimensional electron gas (nDEG, where n=1,2 or 3) induced in the substrate of a MOSFET are crucial to developing effective models for the devices used at CQCT. The dimensionality (1DEG or 2DEG), in particular, determines the density of available electron states, which in turn affects the tunnelling probability through a barrier gate. The effective dimensionality as well as the transport regime are determined by the phase coherence length lφ and the mean free path (mfp) relative to the geometry of the sample.

In addition, at low temperatures in nanoscale structures, a number of quantum interference effects are evident. Weak localisation (WL), due to the interference of time reversed paths (Fig. 2) of electrons, produces a decrease in the conductance, but is suppressed by a critical magnetic field BC. One form of the 2D correction term is given by1

\[ \rho_{xy} = g_0 - \frac{2}{\pi} \ln \left( \frac{1 + \frac{v_f}{v} + \frac{1}{v_f}}{2} \right) \]

Experimental techniques: Two separate MOSFET gates of width 50/100/200nm were fabricated to measure the transverse (Rxy) and longitudinal (Rx) resistances using a 4-point setup (Fig. 3), in a helium dewar (4.2K) and then dilution fridge (mK), at magnetic fields up to 7T.

Results: Rxy

There was a clear slope in Rxy, allowing the carrier density to be determined as a function of top gate voltage (Fig. 4).

Results: Rx

WL resistance peaks in Rx were successfully seen at zero field, suppressed by a magnetic field of BC=0.5T, which was used to calculate the mobility μ. The correction to the conductance was also fit to the above equation1 (Fig. 5).

Conclusion: As both lφ and the mfp were significantly shorter than the gate width, the devices were determined to be in the 2D diffusive regime. The dimensionality was confirmed by the close fits to the 2D correction term. The carrier density was of the order of magnitude expected.