Low-temperature, low-noise and high-speed characterisation of semiconductor nanodevices

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Using the Nanonis Tramea quantum transport measurement system (QTMS) combined with an Oxford Instruments HelioxVL refrigerator (Figure 1), the energy levels of a qubit, formed in a Germanium nanowire have been successfully measured. Due to the low-noise and high-speed of this measurement system, high resolution conductance measurements are produced in short acquisition times.

Introduction

The operation of quantum computers relies on the formation of so called 'qubits', where the state is not constrained to merely 0 and 1 as in traditional binary computers. Instead, each bit of information is represented by the state of a quantum particle, which can be in a superposition of multiple states simultaneously. A wide variety of methods to form qubits are being investigated. In this work, qubits are formed naturally via the spatial confinement of holes. The confinement is provided by nanowires with dimensions close to the natural wavelength of the carrier, as determined by quantum mechanics. The **Nanonis Tramea** is a low-noise, fast QTMS, and also a safe system, using a single ground. It also eliminates the potential for damaging sensitive samples when disconnecting and connecting cables, and ground lines to a variety of single-function instruments in a measurement rack.

Figure 1. **Nanonis Tramea**, and **Heliox**VL

Experiment

A rough schematic of the typical device is illustrated in Figure 2. A wire composed of Germanium is grown on a Silicon substrate and electrical contact is created lithographically. A gate is added to allow a potential to be applied in order to shift the energy levels of the confined hole up or down, to block or permit hole flow through the wire.

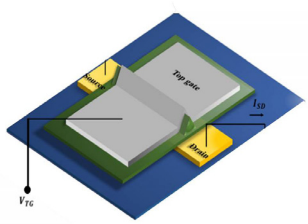

Figure 2. Schematic layout of device.

For this experiment, the entire room temperature measurement electronics requirement was fulfilled using only the **Nanonis Tramea** instrument. The **Nanonis Tramea** system is a fully digital, integrated package that provides the functionality of an oscilloscope, spectrum analyser, voltage sweepers, voltmeters, lock-in amplifiers and function generator, in one compact package. It can also control eight inputs and eight outputs (expandable to 24 and 24) simultaneously in one user interface. As all of this functionality is housed within one unit, the communication speeds and therefore the data acquisition times are much shorter. Specifically, there is no need to incorporate slow bus connections between individual devices that traditional instruments rely on. The connection scheme between the device and the electronics is shown in Figure 3. A current amplifier is connected to the drain contact and its output is sent to an input on the electronics. One output is connected to the source side of the wire and a second output is connected to the top gate along the wire. All of these connections are therefore sourced from one single unit instead of a range of individual instruments (often from different suppliers), tied together using custom software.

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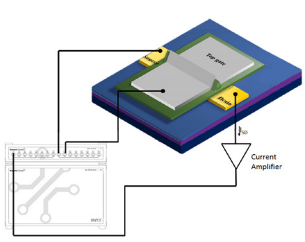

Figure 3. Connection diagram between **Nanonis Tramea** and device.

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Results

The device was mounted to the ^{3}He pot of an Oxford instruments **Heliox**VL ^{3}He system and measured at a temperature of 270 mK. Initial results are presented in Figure 3, where the familiar Coulomb diamonds are visible. As the source-drain potential is swept and a hole can enter the dot, Coulomb repulsion prevents additional carriers from tunnelling into the dot, until a further increase in potential causes an additional energy level to become available for occupation. The fine structure visible in the lower left of the diagram is where the energy levels line up, formed due to the excited states of the qubit, allowing the holes to move through the device. This fine structure was revealed when switching to the Tramea system, compared to our older electronics measurement system composed of multiple instruments. Furthermore, since all of the measurement parameters are downloaded into the Tramea, the entire acquisition proceeds autonomously and at high speed, compared to the traditional methods with software running on a PC, sequentially sending commands to each part of the measurement setup. The **Nanonis Tramea** is now a key instrument in our experimental design, as we are now planning scale up activities to have multiple qubits. As the **Nanonis Tramea** can accommodate 24 inputs and outputs using the same software interface, we do not require additional instrumentation.

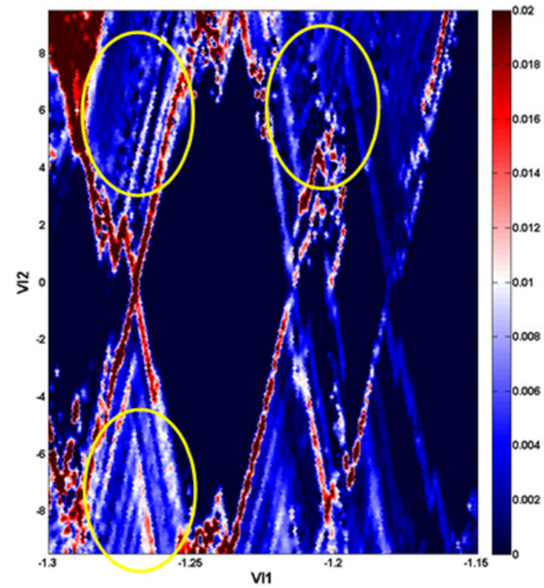

Figure 4. Differential conductance of the nanowire device as a function of the gate (V2) and source-drain (V1) potentials. Note the fine details (yellow ovals) that emerge when using the **Nanonis Tramea** measurement electronics. Note that the excited states (yellow ovals) were not visible with our previous measurement electronics.

Conclusion

We have used the **Nanonis Tramea** to investigate the energy levels of a qubit formed within a nanowire. Preliminary results reveal new details in the conduction through the device, previously obscured by the noise level of our old measurement system. Additionally, the single instrument nature of the **Nanonis Tramea** permits a dramatic increase in acquisition speed by eliminating the slow bus protocol we used previously, when combining individual components (DC voltage sources, lock-in amplifiers, etc.) with a home-built software package. The next step in our research will be to perform these experiments at ultra-low temperatures on a **Triton** Cryofree dilution refrigerator (down to 50 mK), which will require the very low-noise characteristics of the **Nanonis Tramea**.

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