Silicon-Based Single Electron Devices—
a promising avenue towards the realisation of quantum computer

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As the aggressive trend for shrinking the size of transistors and devices are developing, single-electron devices (SEDs), which is also known as quantum dots (QDs) have been proposed for a variety of applications, including quantum metrology (in which the ampere is tied to the electron charge, a fundamental constant of nature), ultra-sensitive electrometers, and more importantly as solid-state quantum bits (qubits) for a quantum supercomputer.

A proposal by Nobel laureate physicists Richard Feynman in 1986 that controllable quantum systems could be utilised to simulate other quantum systems efficiently has sparked great scientific interest and created the field of quantum information processing (QIP) [1]. It is well-known that a classical computer cannot simulate quantum systems efficiently as the dimension of the Hilbert space, i.e., the state space of the quantum system, increases exponentially with the particle number, rendering such problems intractable in classical digital systems. However, it has been shown theoretically that it is possible to simulate a quantum system with a quantum computer efficiently.

This has attracted enormous attention of the scientific community in general; not only can we finally simulate and study the pecularities from various quantum phenoma such as nonlocality and entanglement, we can also harness the power of quantum mechanics for solving NP-hard problems with ease, physically unbreakable quantum cryptography for secure communications, and potentially modelling new medical drugs and protein-folding at exponentially greater speeds to find cure to diseases such as cancer that has been plaguing the world [2,3]. Each benefit mentioned here is a new field of research in itself and the Nobel Prize in physics in 2012 awarded for the research in quantum systems highlights the importance of quantum engineering. The race towards a real quantum computer is on and this can be witnessed by the sprouting of centers for quantum engineering in world-leading universities all over the world in the last two years alone.

There are a number of potential quantum computer candidates, including those based on superconducting resonators [4], ion-traps [5], quantum optics [6], and spintronics [7]. Among these candidates spintronics-based which utilises the intrinsic quantum angular momentum of a single electron, or 'spin' in a silicon quantum dot has shown significant advantages over the other candidates in terms of scalability and robustness towards quantum decoherence. The device fabrication methods here are compatible with the proven existing CMOS technology, making the integration of quantum dots in silicon chips straightforward (see Figure 1). From the fabrication point of view, one needs to be able to build a physical system with a collection of individually-addressable qubits.

Since the qubits here are based on transistors and modern day microprocessors already have billions of transistors per chip, it is a major advantage over other quantum computing candidates in terms of scalability. Unlike classical bits, qubits store information in their quantum states and these states are inherently fragile and susceptible to environmental fluctiations or 'noise'. The noise will interfere with the quantum states and subsequently destroy the stored information, a process widely known as 'decoherence'. That being said, the decoherence time of these spin-based qubits are by far the longest [8-11] of all the candidates known to man. Hence, the information stored in these qubits are relatively long-lived, allowing multiple qubit operations to be performed before the information is lost. Long lifetime also relaxes the requirements to ultrafast (hence more error-prone) qubit operations and error-correction overheads [12, 13].

The intrinsic spin of the electrons in coupled silicon QDs are one of only a handful of natural-occuring quantum two-level systems. These two levels constitute the |0>

Figure 1 Researchers performing resist coating in a class 10 semiconductor nanofabrication cleanroom.

and |1> quantum states of the spin qubit. These individually addressable single electrons can be confined and desired qubit operations can be performed on them by the electrical gating of the tunneling barrier between the QDs that define the qubits (as shown in Figure 2). Similarly, the readout of the quantum states can be done electrically through a single-electron electrometer. Today, silicon-based SEDs are one of the leading candidates for these applications, mostly because of their general attractive attributes including device tunability and stability (lack of charge offset drift) [14-18]. Furthermore, the spin-coherence times in bulk Si can be made very long when the nuclear spin bath is effectively removed through the use of isotopically enriched 28Si if necessary.

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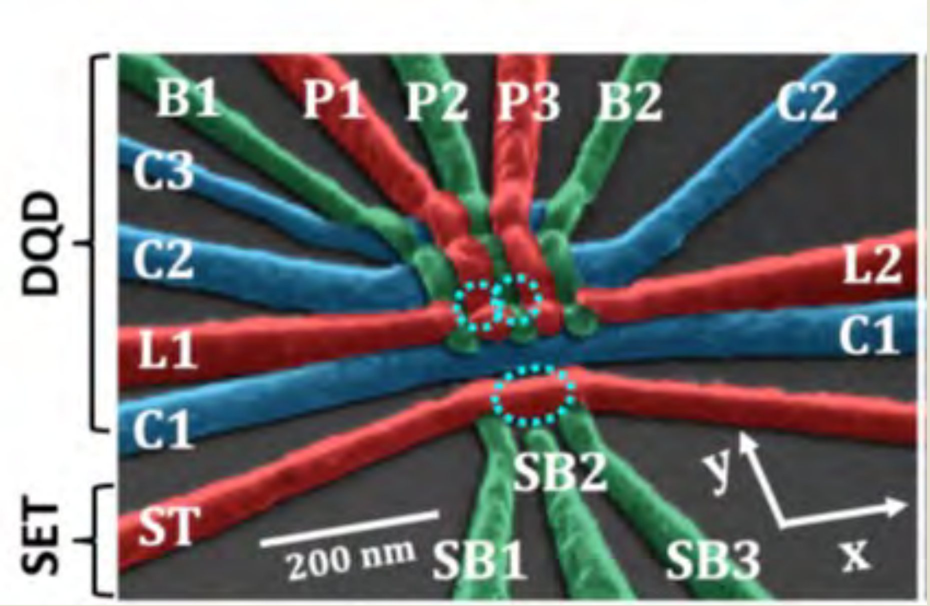

Figure 2 (Top view) Scanning electron microscope (SEM) image of silicon quantum dots, with a charge sensor nearby.

ANNOUNCEMENT

BEWARE OF FALSE IMM CERTIFICATES

There have been cases of false IMM Blaster & Painter Certificates and IMM Coating Inspector Certificates detected at various project locations throughout Malaysia in the past months. IMM Management Committee has initiated a police report and will commence investigations into the origin of the false certificates.

Anyone with knowledge or information pertaining to the issuer or persons purchasing such false IMM certificates are requested to notify the IMM Management Committee through email address admin@iomm.org.my