From Quantum to Optoelectronics: University College London Case Study

We had the privilege to speak with two Senior Research Fellows from UCL who use our **Plasma**Pro® **80** RIE system, presenting their latest research projects related to Quantum and Optoelectronic devices. Reactive Ion Etching offers excellent process control in the fabrication of semiconductor devices and is used in many device manufacturing processes.

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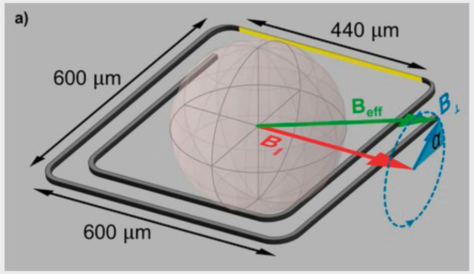
Creating Quantum Memories

Oscar Kennedy, UCLQ Postdoctoral Fellow, focuses on the fabrication of devices for the efficient exchange of quantum information.
The main goal of his research is to create Quantum Memories which are essential to overcome decoherence limitations and scale quantum information systems for more sophisticated computations.

Dr Kennedy implants atomic impurities into silicon. These atomic impurities have electron spin properties which can act as quantum bits, or qubits. "Superconducting resonators interfaced with paramagnetic spin ensembles are used to increase the sensitivity of electron spin resonance experiments and are key elements of microwave quantum memories.[1]

Superconducting resonators are fabricated on silicon using standard photolithography techniques



Reference 1: Schematic of the lumped element NbN thin-film resonator and the applied magnetic field Beff with two components

with Nb or NbN as the superconducting metal.
The resonators are designed and fabricated to have a resonant frequency which can be tuned by a magnetic field component introduced in an orientation perpendicular to the thin film resonator.
This tunability enables optimal coupling between the superconducting resonator and the spin system.

Although substantial advances have been made for spin-based quantum memories, many challenges remain. Currently, the coupling efficiency between the resonator and spin system is limited, most likely due to dangling bonds at the Si/SiO_2 interface. These devices can be used to further our understanding of spin-resonator coupling in order to overcome current limitations and may one day be used for robust and dynamic quantum memories in next-generation quantum information systems.

"This relates to the circuit design, the nature of your defects and the quality of your superconducting architecture", as Dr Kennedy has observed.

Fabrication Process of Superconducting Circuit

In previous research, Dr Kennedy used lift-off techniques for the fabrication of the superconducting architecture. However, as he states "some of the better results for quantum devices have been achieved by etching rather than lift-off techniques".

In his latest research project, the superconducting resonator was fabricated "by electron beam lithography and reactive ion etching into a ≈50 nm thick NbN film, sputtered on a 250 µm thick high-resistivity (> 5000 Ω cm) n-type Si substrate".[1]

"Some of the better results for quantum devices have been achieved by etching rather than lift-off techniques".

Etch processes are superior for many quantum device fabrication applications because there is no need to apply photoresist to the bare Silicon surface, thus avoiding lossy organic residues at the metal-substrate interface. These residues cannot be removed in a lift-off process because some photoresist must be present on the wafer at the time of metal deposition in a lift-off process, which makes it impossible to use aggressive cleaning techniques to remove organic residue at the similar surface where the superconductor will remain after deposition.

Oxford Instruments' **Plasma**Pro® 80 RIE system is used to create the superconducting circuit by etching the superconducting NbN film. "With the **Plasma**Pro 80 RIE, you can proceed with very aggressive chemical cleaning and then immediately you can deposit your superconductor on top of your substrate. It's fast to use and straightforward with powerful and immediate results.", according to Dr Kennedy.

Our reactive ion etching system provides an easy, quick, and well-developed dry etching process to achieve a very clean interface between your superconductor and your substrate, avoiding any residues and contamination that you might have with other processes such as lift-off.

"The Oxford RIE system has a real quality of life benefit, where you load the wafers into the system and within an hour or two you have completed your process".

Optical Networks – The future of Communication

Dr Wing Ng is a Senior Research Fellow in nanofabrication and optoelectronics at the Department of Electronic & Electrical Engineering at UCL. One of his projects is focused on optical communication networks, specifically in the design and fabrication of Indium Phosphide (InP) devices for MEMS Optical Buffering.

Optical networks are the future of data communication as signals travels faster through optical fibre than electrical wire. The future realisation of all optical network will increase the speed of communication, and the capacity for information/data sharing.

As the signal in optical fibres travels between multiple destinations and devices, the light needs to switch the data to separate destinations. If two or more signals arrive at the optical switch at the same time, one or more of the signals must wait while the first signal is switched. The current technology requires this signal to be converted into electrical domain before storing it in an electronic memory. This optical-electrical signal conversion is slow and requires energy. Dr Ng's research is dedicated to finding a way to store this information in optical domain using an optical buffer, a device which is capable of temporary storing light. This technology would eliminate the need of electrical-optical signal conversion, and hence more energy efficient.

Requirements for the optimal device performance

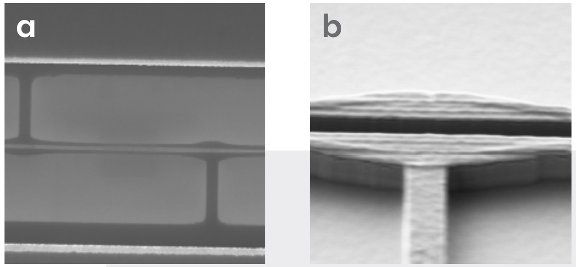
An optical buffer system provides optical delay (memory) for optical switching systems. Current technology relies on optical fibre loop which is physically big and not flexible. The development of chip based optical buffer will greatly minimise the footprint of optical delay system as well as providing flexibility of tuning the optical delay time.

Dr Ng and his colleagues designed a chip-based optical buffer, and the heart of the system is a pair of suspended parallel waveguides fabricated out of indium phosphide material (InP). The gap between the waveguides can be tuned using MEMS technique to provide different optical delay times.

"The optical delay time for our system depends on the separation distance between the two parallel waveguides, as well as the overall length of the waveguides", says Dr Ng.

Indium Phosphide (InP) Waveguides Fabrication

Dr Wing Ng has achieved this by using reactive ion etching. After patterning the waveguides with electron beam lithography, "the structure was etched by reactive ion etching (RIE) with a cyclic methane-hydrogen/oxygen plasma", a dry etching process which allows isotropic and anisotropic material removal.



Reference 2: SEM images of (a) top view of the waveguide and pillar pattern after electron beam lithography, (b) side view of the reactive ion etched pillar section of the structure.

"Oxford's RIE system offers high flexibility in the process and excellent control of the gases and the power of plasma".

The **Plasma**Pro® **80** RIE system enabled Dr Ng to accurately pattern the 50 nm gap between the pair of waveguides with smooth sidewalls and a sidewall angle above 80°, without leaving any residual resist on the waveguide surfaces. "Controlling the size of the air gap during fabrication is very critical for the device function."[2]

Our reactive ion etching system achieves smooth waveguide sidewalls, which is important to minimize light leakage and propagation losses in optoelectronic devices. As Dr Ng states, "Oxford's RIE system offers high flexibility in the process and excellent control of the gases and the power of plasma".

III-V semiconductors such as InP and Gallium Arsenide (GaAs) can be efficiently etched with our **Plasma**Pro **80** RIE system, which allows engineers and physicists to control both ion density and energy, as well as the substrate temperature.

Research and Future Innovations

Both Research Fellows, Dr Kennedy and Dr Ng from UCL continue their projects in the Quantum and Optoelectronics research fields, respectively.

The development of quantum memories and devices for exchanging quantum information between microwave and spin systems will continue to be the main goal of Dr. Kennedy. His current project is about investigating which atomic defects in silicon are most suitable for high efficiency quantum memories.

Dr Ng's current research project focuses on the design and control of the wetting properties of III-V semiconductor surfaces, specifically of indium phosphide-based multilayer materials. This is critical for "the development of coating-free waterproof optoelectronic and microelectronic components where the coating may hinder the performance of such devices and cause problems with semiconductor fabrication compatibility".[3]

Oxford Instruments Plasma Technology will continue to support innovative research projects by providing customised solutions and continuously improving fabrication processes.

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PlasmaPro **80** RIE

References

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