University of Glasgow case study: Optimising Process Fabrication of Superconducting Qubits

November 2021

Optimising Process Fabrication of Superconducting Qubits

With over 11 years of collaboration with University of Glasgow, we continue to support the innovative fabrication processes for power semiconductor, optoelectronic, quantum and many more devices that take place at the state-of-the-art James Watt Nanofabrication Centre (JWNC) cleanroom within the university.

We had a highly informative conversation with two researchers from the University of Glasgow who have shared their innovative projects related to the fabrication of superconducting qubits. Dr Jharna Paul is a Research Associate and Valentino Seferai is a PhD student within the Quantum Circuits Group which is led by Professor Martin Weides. Both researchers use the Oxford Instruments **Plasma**Pro® **100** Cobra ICP RIE system for the fabrication of superconducting qubits.

Developing Superconducting Qubits

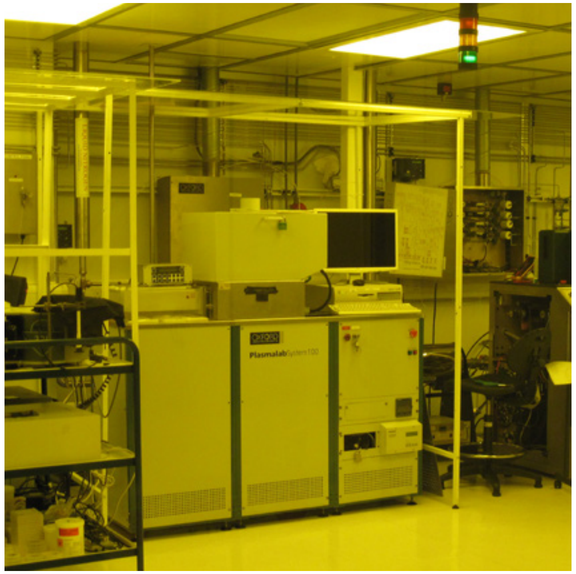
In one of their previous projects in association with other researchers, Dr Jharna and Valentino have focused on the creation of integrated and highly coherent cavity magnon–polariton systems. These have strongly coupled spin-wave and microwave photonic components, making them a good candidate for quantum information processing with hybrid quantum devices. The result of this research was "the achievement of strong coupling on chip devices comprising a superconducting resonator and a YIG sample at sub-Kelvin temperatures"[1]. The superconducting resonators were fabricated from niobium nitride (NbN) films, using electron-beam lithography and Oxford Instruments' reactive ion etching systems.

Dr Jharna's current research involves wafer-scale nanofabrication of quantum qubit devices along with integrated on-chip components for quantum information processing and computing applications. The first stage of the fabrication process includes the deposition of superconducting metal on intrinsically doped silicon wafers with a magnetron sputter tool. The metal is then patterned using e-beam lithography and the exposed metal etched using Oxford Instruments' **Plasma**Pro® **100** Cobra ICP system which achieves a clean etch surface with high selectivity to the underlying substrate.

Valentino is focussed on the fabrication of superconducting quantum circuits, using Josephson junctions which are well-established for the construction of qubits in quantum information processing applications. Previously he was involved in a research project led by Professor Martin Weides in which the research team achieved "good coherence properties of four transmon qubits with subtractive Josephson junctions"[2], where the qubit life and coherence time of their best device was more than 20 µs, a significant step for future large-scale fabrication of superconducting circuits.

Currently, Valentino Seferai is optimising another fabrication recipe for an emerging material, using tantalum to make superconducting resonators which provides the high-quality factors to better control the qubits.

"Once you optimise the process, the ICP system is reliable with repeatable results".



Process Optimisation is the key for successful research

For both researchers, meticulous process optimisation is fundamental. They usually develop their own recipes which requires deep understanding of the process.

"We use Oxford Instruments **Plasma**Pro® **100** Cobra ICP etching system, as you can effectively control the plasma, the power, the gas delivery, the chamber pressure and the substrate temperature", Dr Jharna Paul states, and she continues "Once you optimise the process, the ICP system is reliable with repeatable results".

The research team investigates dry etch recipes that produce high coherence qubit devices in order to build the superconducting circuit and this device fabrication needs high selectivity and accurate control of the plasma. The goal is to etch the metals and other materials as cleanly as possible without leaving any residues and without damaging the metals in order to get a good etch profile. The **Plasma**Pro® **100** Cobra ICP "effectively controls the etch rate and makes the process more stable", as stated by Valentino.

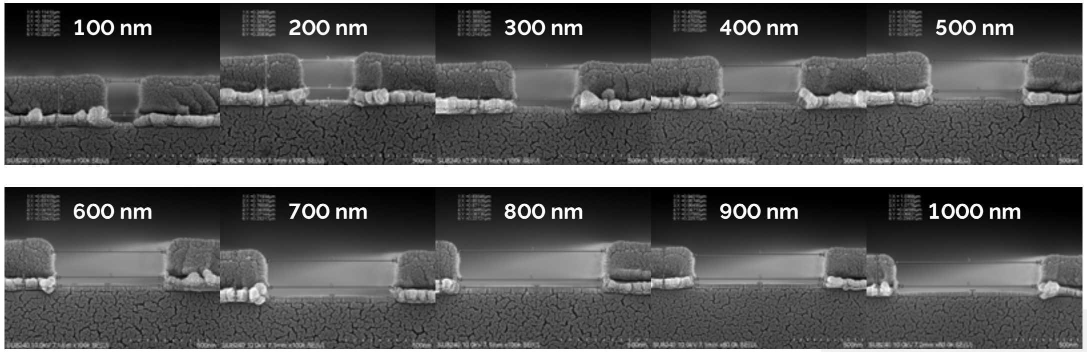


Figure 1:Profile Post Etch of Al with Cl_2/ HBr/ BCl_3. Very high selectivity to ZEP mask. Al etch profile circa > 88. Courtesy of Dr James Grant, Senior Plasma Process Research Engineer in James Watt Nanofabrication Centre.

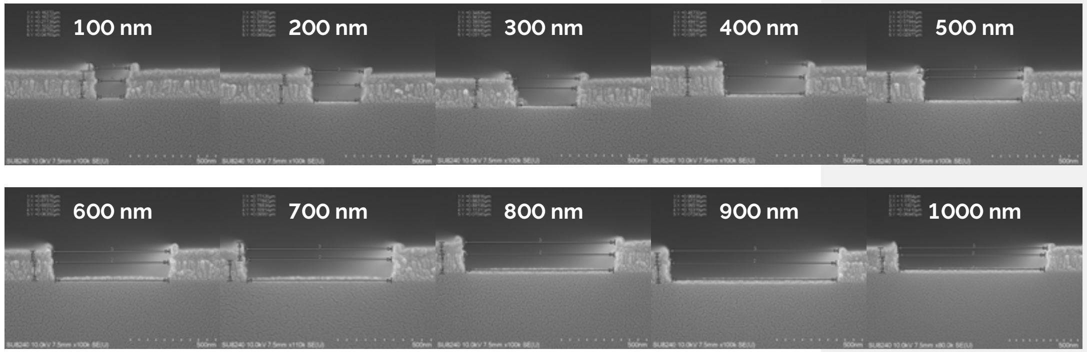


Figure 2: Profile Post Etch of NbN with CF_4 Ar RIE (ZEP mask still on). NbN etch profile circa > 88. Courtesy of Dr James Grant, Senior Plasma Process Research Engineer in James Watt Nanofabrication Centre.

The PlasmaPro® 100 Cobra ICP "effectively controls the etch rate and makes the process more stable".

Oxford Instruments **Plasma**Pro® **100** Cobra ICP provides application related flexibility with controlled high etch rates for deep features and low etch rates for shallow features with high precision and low damage. According to Dr Jharna "it produces high quality vertical sidewalls which are very important to minimise losses".

In the images to the left, the Quantum Circuits Group has successfully achieved a vertical etch in the circuits with Oxford Instruments' ICP system, etching Al and NbN thin films.

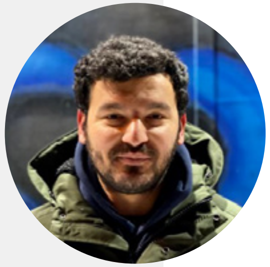
Finally, by using endpoint detectors where the researchers can monitor the process in real-time, Dr Jharna and the research team can detect the point where all the etched film has been removed, achieving excellent reproducibility.

Driving the Future of Quantum Industry

Recently, the University of Glasgow launched a dedicated Centre for fundamental and translational research in quantum technology[3] for a wide range of applications including computing, information processing, photonics and sensors.

For device fabrication, the University of Glasgow uses various plasma systems, including **Plasma**Pro® **100** RIE and **FlexAL**® ALD system. Oxford Instruments is an intrinsic part of the quantum community and to enable the quantum devices to be characterised at millikelvin temperatures, in January 2021, the university announced the purchase of Oxford Instruments' next generation **Cryofree**® refrigerator, **Proteox**. Oxford Instruments is a long-term strategic partner with the university, and we will continue to support in their cutting-edge research and development projects into quantum and many other devices.

Dr Jharna Paul
Research Associate,
University of Glasgow



Valentino Seferai
PhD student, University of Glasgow

References

1. Appl. Phys. Lett. 119, 033502 (2021); https://doi.org/10.1063/5.0054837 Submitted: 22 April 2021. Accepted: 24 June 2021. Published Online: 19 July 2021

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3. University of Glasgow Launches Centre for Quantum Technology, University of Glasgow, 29 September 2021, https://futurescot.com/scottish-university-launches-quantum-technology-centre/

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