IONOPTIKA
ion beam technology

Q-One

Advanced platform for quantum and nanoscale materials engineering

www.ionoptika.com

Q-One

Q-One™ is a state-of-the-art focused ion beam platform for advanced device fabrication and nanoscale materials engineering. Featuring deterministic single ion implantation, Q-One is the world's first instrument specifically designed to meet the demanding requirements of quantum research.

Ground-breaking innovations enable the implantation of single ions into a twenty-nanometre area with up to 98% confidence.

Liquid metal source technology allows the user to select multiple ions from a single source with isotopic resolution. Alloy compositions are available for many elements, including rare earth and transition metal species. A plasma source is also available for gaseous elements.

The Q-One platform includes

- High-resolution mass-filtered focused ion beam
- Deterministic single ion detection with up to 98% detection efficiency
- Choice of liquid metal or plasma ion source
- Best-in-class ion selection and a wide range of implant species
- Femtoamp beam currents for accurate single-ion events
- Nanometre-precision stage with up to 6-inch wafer handling
- Proprietary implantation and lithography software

"Q-One is the most advanced system for the fabrication of quantum devices and advanced materials engineering."

Deterministic Implantation

Deterministic single-ion implantation means placing a single ion into a substrate with incredible accuracy and knowing that implantation has occurred. Q-One uses DetectION™ technology, Ionoptika's ultra-sensitive post-implant detection system, to detect the signals generated upon each ion impact.

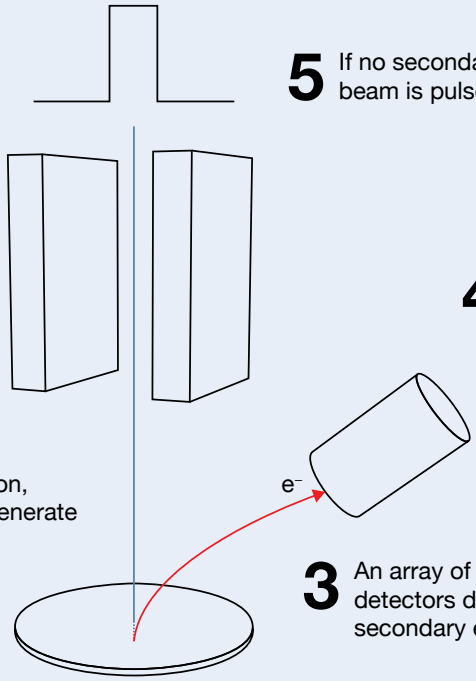
Without the means to detect each implant event, implanting single ions with precision would not be possible.

The DetectION™ system offers speed and scalability and requires no complex pre-fabrication. So you can choose the implant species and target material without hindrance.

The DetectION™ System

1 The femtoamp ion beam is pulsed for a few tens of nanoseconds.

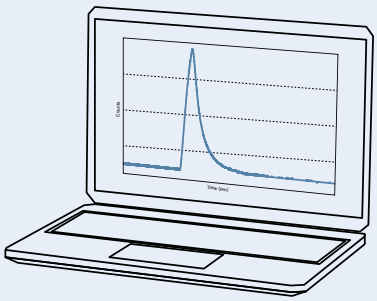
5 If no secondary electrons are detected, the beam is pulsed again until an event occurs.

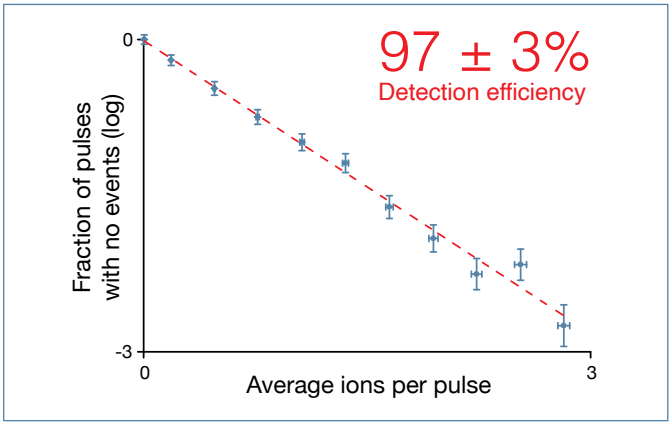


4 Once the detected pulse passes a threshold value, the system logs it as an implant event and moves to the next position.

2 If the pulse contains an ion, it will hit the target and generate secondary electrons.

3 An array of high-gain detectors detect the secondary electrons.





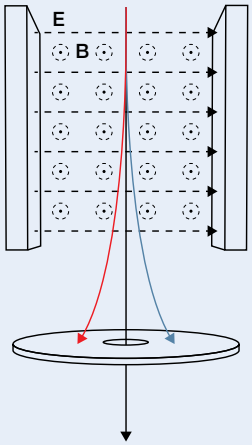
If the detection efficiency is low or does not detect every single event, two or more ions may impact the same location, causing device failure. That is why we work tirelessly to reach the highest efficiency possible – up to 98%!

Q-**One** at a glance

A Wide Range of Species

Q-One offers a wide range of elements for implantation. The liquid metal ion source (LMIS) technology generates multiple ions of different elements in a single source, including clusters and multiply charged species. The built-in Wien (mass) filter allows only the species of interest through, with high-resolution selection down to individual isotopes (m/Δm = 300).

The Wien Filter
Perpendicular electric (E) and magnetic (B) fields filter particles based on their velocity.

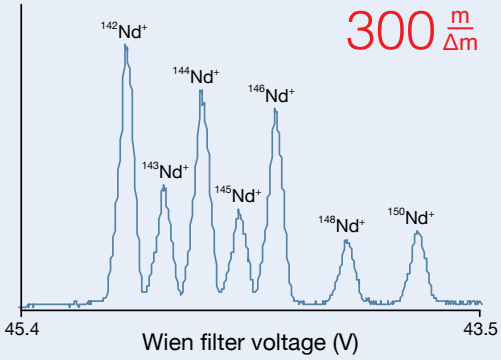


Many implant species are available for use with the Q-one, with source alloys containing Si, Sn, Sb, Au, Bi, Nd and Er amongst others.

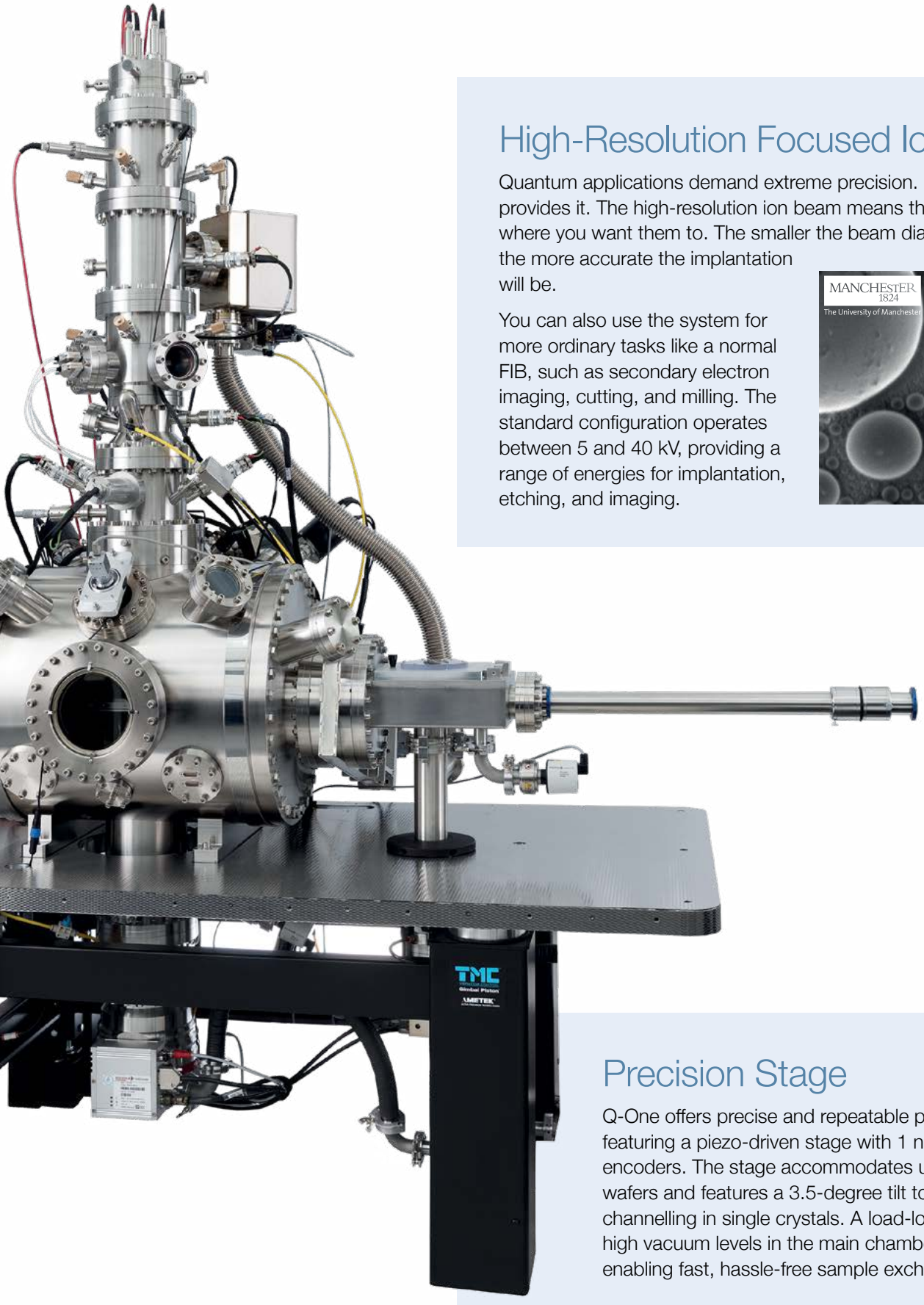
Each Liquid Metal Alloy Ion Source (LMAIS) is developed and optimised for maximum stability and longevity.

A separate plasma ion source is also available for H, N, O and other gaseous elements.

We are continually developing new sources, visit **www.ionoptika.com/q-one/** for an up-to-date list of available elements.



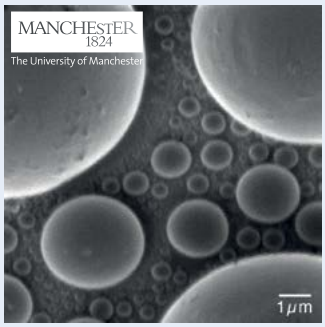
Wien filter scan of a neodymium source. Q-One features best-in-class ion selection down to individual isotopes.



High-Resolution Focused Ion Beam

Quantum applications demand extreme precision. Q-One provides it. The high-resolution ion beam means the ions go where you want them to. The smaller the beam diameter, the more accurate the implantation will be.

You can also use the system for more ordinary tasks like a normal FIB, such as secondary electron imaging, cutting, and milling. The standard configuration operates between 5 and 40 kV, providing a range of energies for implantation, etching, and imaging.



Precision Stage

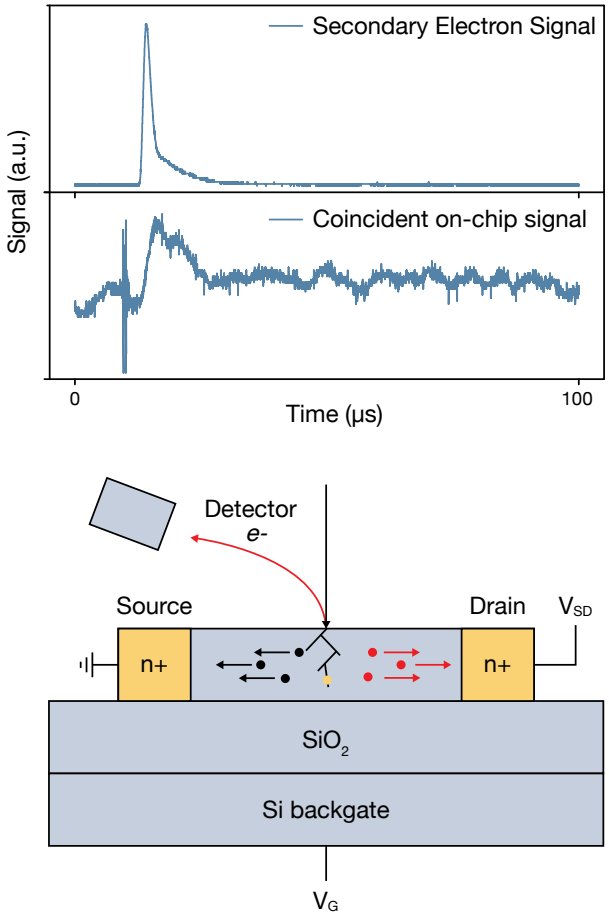
Q-One offers precise and repeatable positioning, featuring a piezo-driven stage with 1 nm optical encoders. The stage accommodates up to 6-inch wafers and features a 3.5-degree tilt to reduce channelling in single crystals. A load-lock maintains high vacuum levels in the main chamber while enabling fast, hassle-free sample exchange.

Applications

Quantum Technology

Single impurity atoms embedded in a semiconductor matrix show great promise as quantum bits (qubits). Capable of producing vast arrays of identical qubits, single ion implantation is a key route to repeatable manufacture of these and other quantum devices.

However, the tolerances are extreme – each atom must be placed very precisely, sometimes as little as 20 nm from its neighbour. Q-One is the only tool designed for this application with specifications targeted at these extreme requirements. The system implants single ions with an accuracy of up to 20 nm and a range of depths.



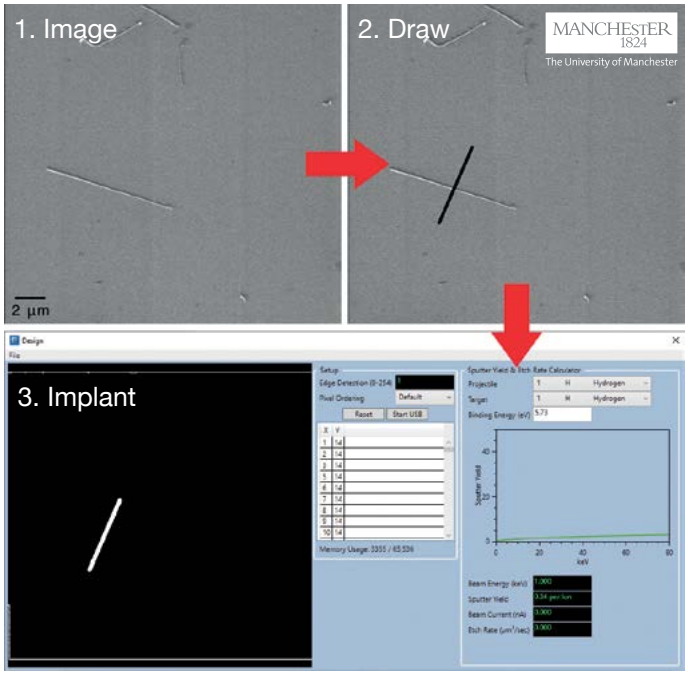
Implanting 25 keV Bi ions into a 1 µm wide channel SOI-FET verifies the detection by measuring coincident secondary electron and on-chip signals.

Q-One is also ideal for forming nitrogen-vacancy (NV) centres in diamond and other point defects in semiconductors. The NV centre is a source of single photons, another candidate for quantum computing and other quantum technologies. With the plasma ion source option, Q-One can implant gaseous elements, including nitrogen, oxygen, hydrogen, and helium.

Doping Nanomaterials

Q-One is not limited to implanting single ions. Implant with any desired ion dose into any location, and even implant custom areas or shapes using the proprietary software.

Doping nanomaterials such as nanowires or quantum dots with different elements can alter their properties. Q-One opens up a world of possibilities by allowing you to target individual nanomaterials and explore different behaviours using a wide variety of dopants.



Create custom implant designs using reference images to dope materials such as nanowires and quantum dots.

Ion Lithography

Q-One allows the user to perform direct-write lithography, just like a normal FIB, but with a wider range of species and greater control over ion dose. Use heavy elements such as bismuth for highly efficient sputtering or light elements such as hydrogen for resist-based ion lithography, even down to single-ion events.

Optical image of a bismuth implant into silicon. The proprietary implantation software allows the user to create custom designs.

"What otherwise would take days of meticulous preparation, Q-One achieves in seconds."

Specifications*

Ion Beam	Liquid metal ion source	Plasma ion source
Energy range	10 – 25 kV or 10 – 40 kV	5 – 30 kV
Min. spot size	20 nm	40 nm
Beam current	50 fA – 1 nA	50 fA – 1 nA
Max. scan field	> 500 µm	> 500 µm
Wien filter resolution	300 m/Δm	N/A

System	
Detection efficiency†	97 ± 3%
Repetition rate	100 Hz
Stage precision	Down to 5 nm
Vacuum	< $5x10^{-8}$ mbar
Max. sample size	Up to 6-inch wafer

** The specifications listed here are for illustration purposes only and may not be accurate for all ion species.*
† Efficiencies will vary depending on the target material and implant species.

Q-One is a versatile and adaptive system designed for researchers to investigate the seemingly endless number of theoretical quantum devices. If you have specific requirements not met here, contact us today. We would be happy to discuss configuring a system to meet your needs.

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“At this point in time I still do not know of a competing instrument with the capabilities provided by the Q-One product and would like to offer my praise for the instrument that Ionoptika have designed and built to our requirements.”

Professor Roger Webb

Professor of Ion Beam Physics & Director of the UK National Ion Beam Centre

Established in 1994, Ionoptika are specialists in ion beam technology. Our mission is to provide innovative ion beam systems and instrumentation that drive discovery in biomedical, quantum, and materials sciences.

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