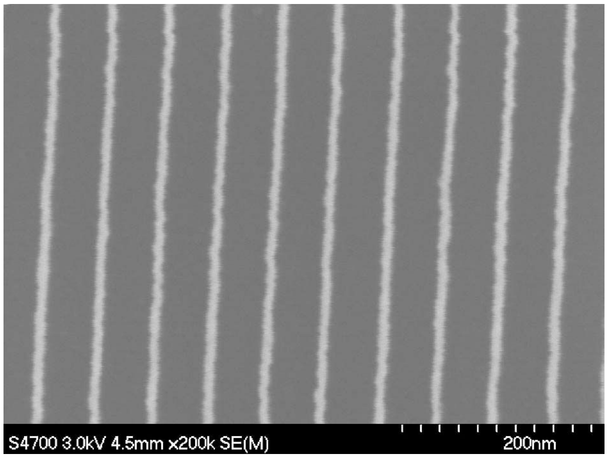
The James Watt
Nanofabrication Centre

Examples of electron beam lithography applications at Glasgow University

1. *Small features*
2. *Novel processing*
3. *Micromachining*
4. *Patterning of magnetic materials*
5. *Applications in optics*
6. *Dot arrays for biology*
7. *Resist characterisation*
8. *Ultrafast systems*
9. *Photomask and substrates*

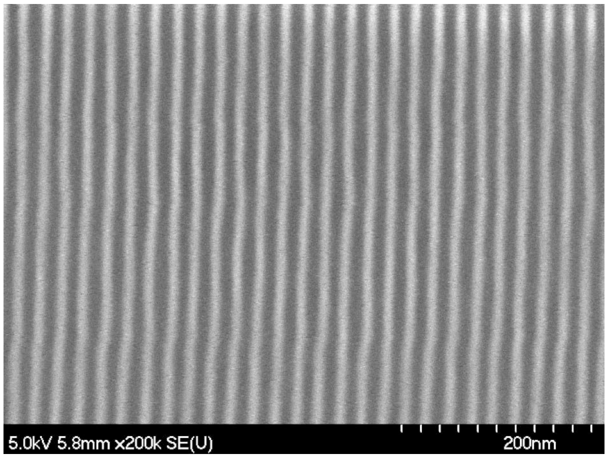
1.0 Electron beam lithography and small features

There is often a need for really small patterned feature sizes such as the sub 10 nm lines shown here written in hydrogen silsesquioxane (HSQ) flowable oxide which acts as negative tone electron beam resist. The patterns were written using our VB6 UHR EWF lithography tool and the lines extend unbroken over several mm.



10 nm lines in HSQ

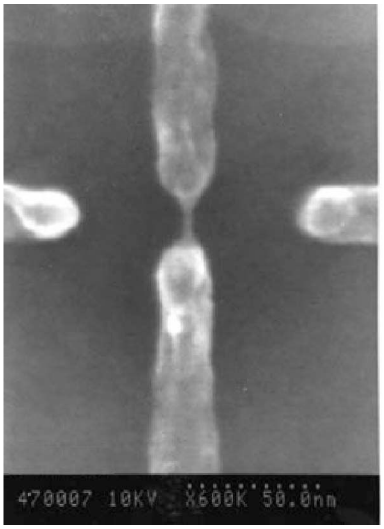
We have also used HSQ to pattern diamond and silicon carbide substrates with sub 10 nm lines. Critical point drying methods were used to achieve high aspect ratio features and these were etched into the substrates and used to transfer patterns into metal films by nanoimprint lithography. The following shows a 23 nm period grating in HSQ- one of the smallest gratings in the world.



23 nm period grating in HSQ on diamond

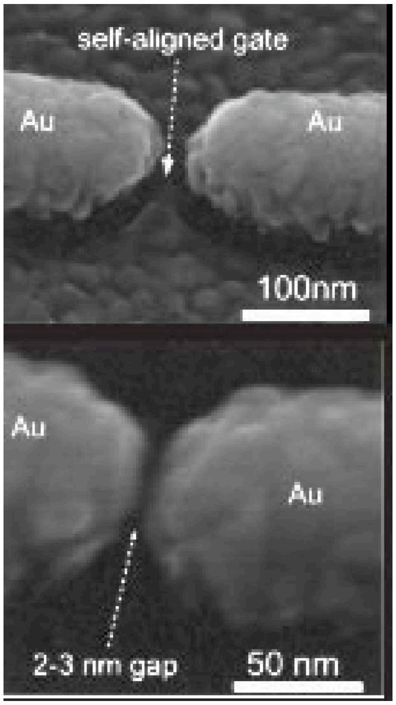
2.0 Electron beam lithography and novel processing

At Glasgow one of our strengths is process development and we are keen to embark on new technical and scientific challenges. Sometimes novel methods need to be developed to accomplish what we set out to do. Here we show one of several 3 nm NiCr wires which were fabricated by skipping pixels in the electron beam lithography patterning process. This structure featured in the Guiness Book of Records for some time.



3 nm NiCr wire

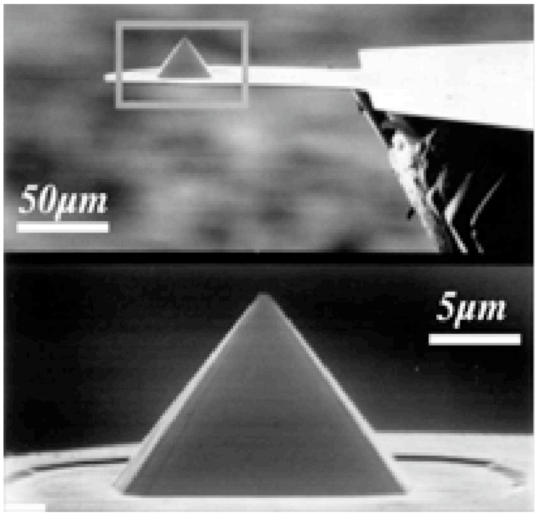
The fabrication of nanoscale gaps between metallic electrodes is particularly challenging and interesting for the study of molecules and metallic nanocrystals . At Glasgow novel methods have been developed (see Spotlight for more detail) using conventional electron beam lithography to produce gaps as small as 1 nm.



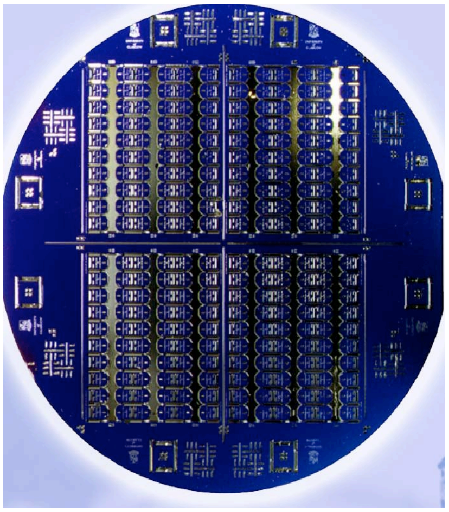
sub 5 nm gaps between metal electrodes

3.0 Electron beam lithography and micromachining

At Glasgow electron beam lithography is used extensively in micromachining applications and these include the development of full wafer processing methods for the fabrication of bespoke cantilevers with a range of sensors including Hall bars and thermocouples. To do this a number of lithography had to be overcome

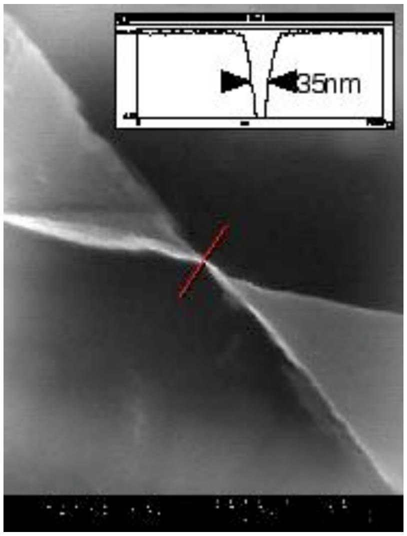


Wet etched pyramid on cantilever

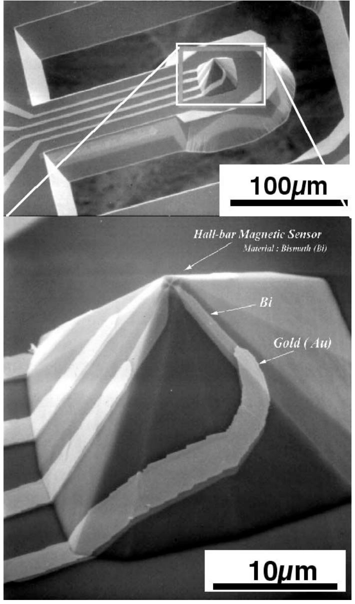


Full wafer fabrication process

To fabricate metal contacts up the steep sides of Si pyramids produced by selective wet chemical etching methods, resist float coating techniques had to be developed to coat pyramid surfaces with a uniform layer of ebeam resist. To overcome beam focus problems which arise as the electron beam moves over pyramids, the ebeam machine control software has been modified. Pattern alignment is also critical. Hall bars with 35nm wires have been fabricated on pyramids in this way.



35 nm Hall bar wire

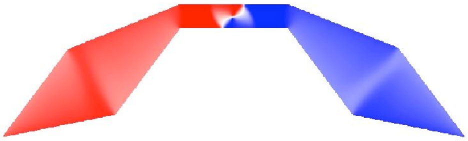


Hall bar on pyramid

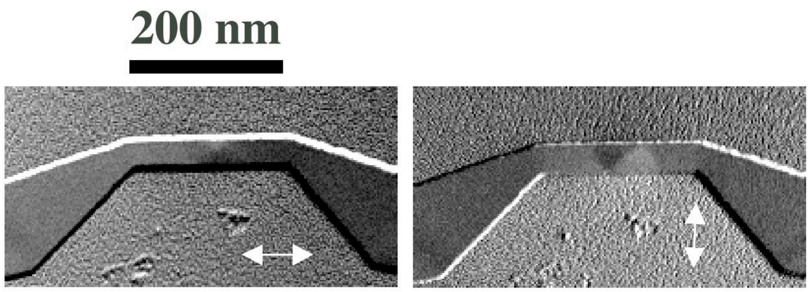
4.0 Electron beam lithography and the patterning of magnetic materials

The Solid State Physics group in the Department of Physics and Astronomy are studying very small magnetic elements and magnetic multilayer films since these display exciting properties that are not found in bulk magnetic material or simple films. Applications are in high density information storage, sensors and logic applications. Fabrication of magnetic elements is carried out using the high resolution electron beam lithography facilities at the JWNC. Understanding the properties of fabricated magnetic elements is scientifically challenging and is done using comprehensive electron and ion beam instrumentation together with scanned probe microscopy facilities within the Department of Physics and Astronomy.

The following compares a micromagnetic simulation of a head to head domain wall trap structure with actual magnetic images of fabricated domain wall trap structures subjected to magnetic induction components in the directions indicated by arrows. In the centre is a 10 nm vortex verified by experiment.



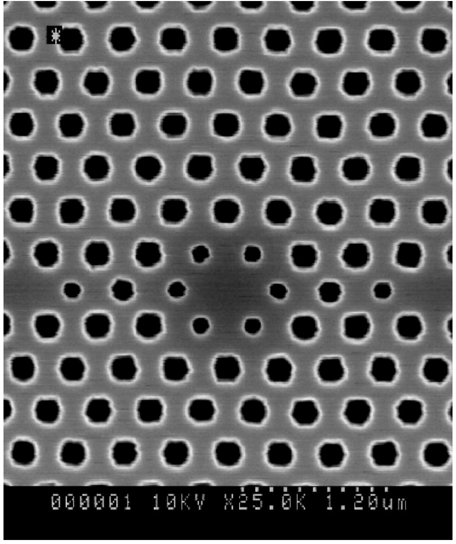
Micromagnetic simulation of a head to head domain wall in a domain wall trap structure



Magnetic images of a domain wall trap structure subjected to magnetic induction components in the directions indicated by the arrows. In the centre is a 10 nm vortex verified by experiment

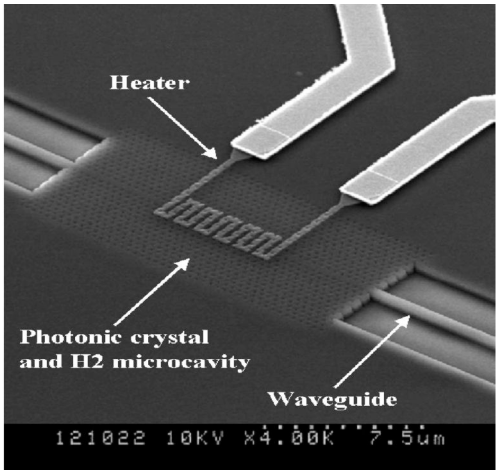
5.0 Electron beam lithography and applications in Optics

The Optoelectronics Research Group are investigating the interaction of light with photonic crystals at submicron dimensions. Potential applications are in telecommunications , optical computing , photo-biology, photo medicine and sensors. 1D and 2D periodic photonic crystals and photonic wires based on silicon-on –insulator and epitaxial III-Vsemiconductor waveguide material are being realized using electron beam lithography. See Spotlight for more detail. Particular challenges are to pattern large arrays of well defined holes with uniform separation between holes. This has been achieved using both positive and negative tone resists. Pattern positioning accuracy of our VB6 UHR EWF lithography tool is 0.5 nm, Here we show a photonic crystal microcavity fabricated with 210 nm holes and with 150 nm confinement mirror holes at the input and output of a channel waveguide.



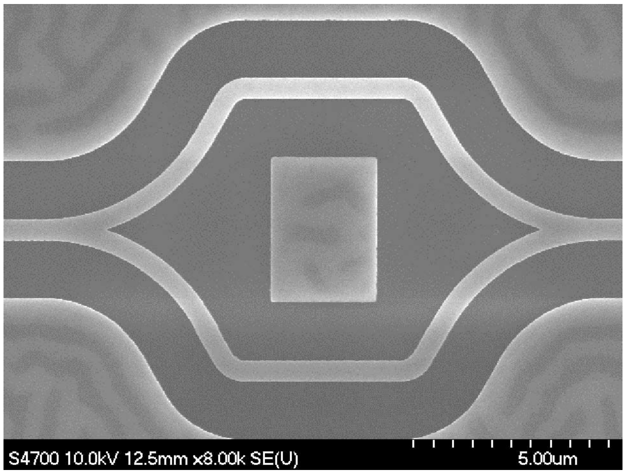
Photonic crystal microcavity with 210 nm holes and 150 nm confinement mirror holes

The electro-optic and thermo-optic properties of these structures is being studied as a means of controlling their behaviour



Photonic crystal microcavity with heater

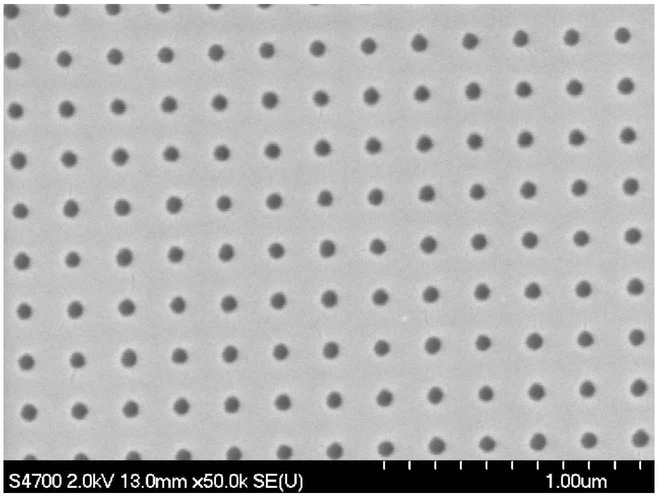
Devices can be realised that are extremely compact and function as channel waveguides, microcavities and Bragg gratings. Here we illustrate a Mach-Zehnder structure made from 500 nm wide photonic wires in silicon on insulator. In integrated optics it can be employed as a modulator



Mach-Zehnder structure made from 500 nm photonic wires

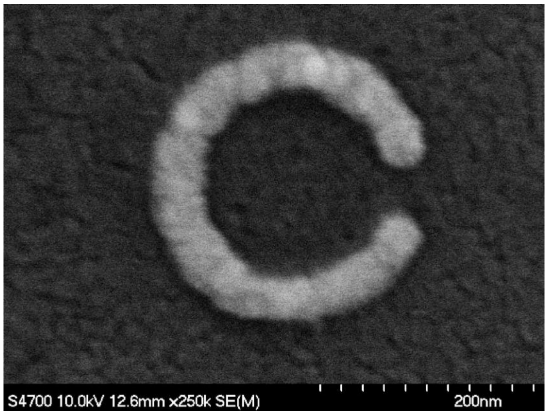
6.0 Electron beam lithography and patterning dot arrays for Biology

At Glasgow biologists are interested in using nanopatterns to elicit specific responses from cells for medical applications and envisage this as a promising way to develop bioactive implant materials for hip, knee and maxillofacial applications. They are also interested in nanotopography to study how external signals are passed to the cells DNA and converted into observed responses such as adhesion and genomic changes. See Spotlight for more detail. Cells commonly have dimensions on the micron scale but are known to respond to pattern features on the nanometre scale. Novel pattern writing strategies have been developed at Glasgow to fabricate large arrays of well defined dots with minimum field pattern stitching.

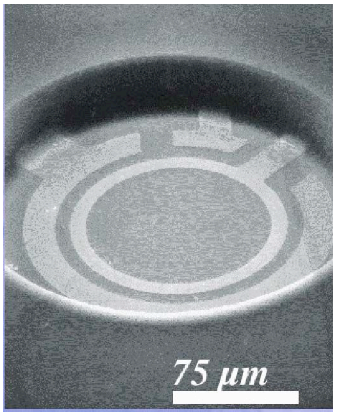


Array of 30 nm dots with 200 nm pitch in PMMA

Above we show an array of 30 nm pits on a 200 nm pitch. Methods have been developed to produce electroformed shims from these types of patterns and they are used with mould injection and nanoimprint lithography to produce large numbers of textured polymer surfaces for biology experiments.



300 nm metal split ring with 40 nm gap

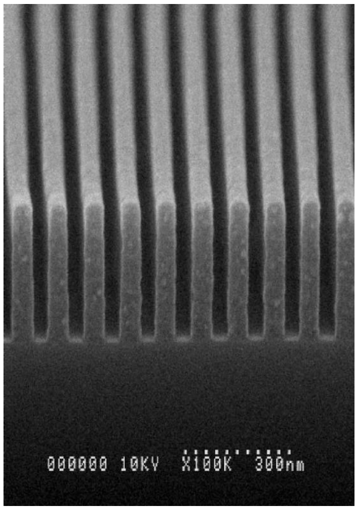


Picolitre cavity

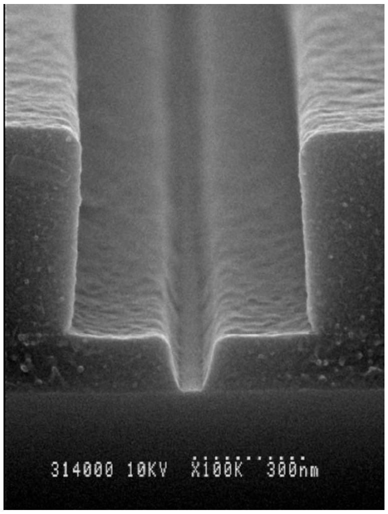
Micro and nanofabrication technology has many applications in bioelectronics. Above right we show a picolitre sized cavity used to study the electrical properties of cells. To the left is one of an array of 300 nm metal split rings each with with a 40 nm gap and used in biosensor applications

7.0 Electron beam lithography and resist characterisation for process development

Resist materials are critical for reliable micro and nanofabrication . Important considerations are the resist tone, sensitivity to exposure, resistance to wet and dry etch processing and the minimum feature size which can be defined in the resist. Much of the early work done using electron beam lithography made use of polymethylmethacrylate (PMMA) and this still remains one of the most useful resist materials today.

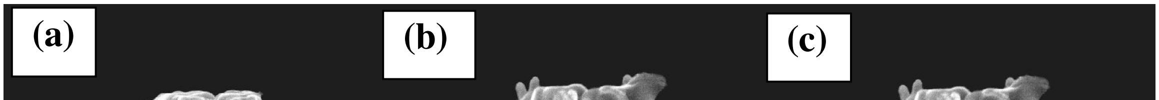


50 nm lines and spaces in ZEP 520



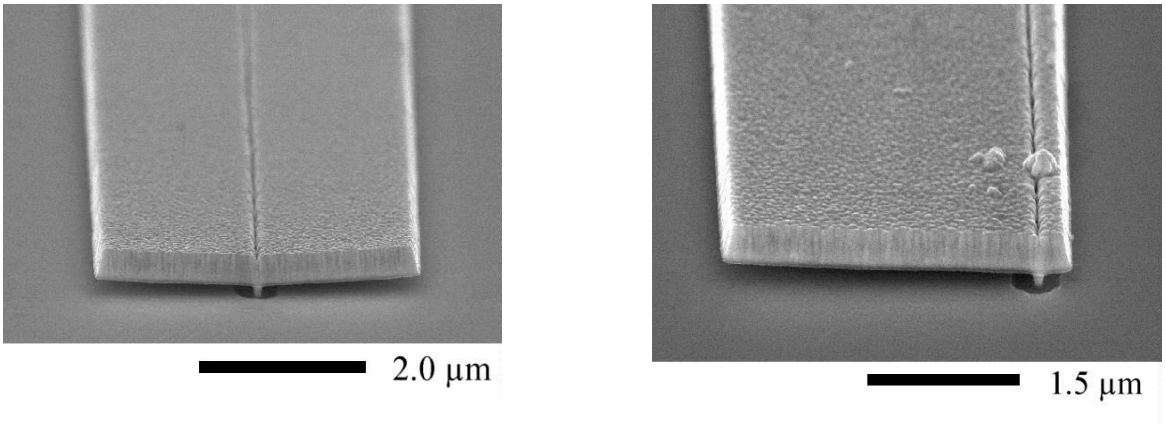
T-shaped profile in ZEP/UVIII

To improve pattern writing times and to meet new challenges in nanofabrication Glasgow has characterised many different types of resist for electron beam lithography applications. This includes DUV resist, chemically amplified resists and copolymers. Above left we show 50 nm lines and spaces defined in ZEP520 with a 7:1 aspect ratio. Multiple layer resist stacks utilising resists with different sensitivity allows three dimensional patterned features to be formed in a single lithography step as shown above. Such resist features are commonly metallised and used to produce T shaped gates for our program of research on ultrafast systems. Multistage development procedures have also been devised to ensure there is effective pattern clearout of both the head and the foot of such structures.



Metal T shaped gates with footwidths of 30 nm , 40 nm and 50 nm

Above we illustrate the fabrication of metal T shaped gates with footwidths of 30 nm , 40 nm and 50 nm . Below we show how large headed T shaped structures can be formed by careful selection and application of electron beam exposure

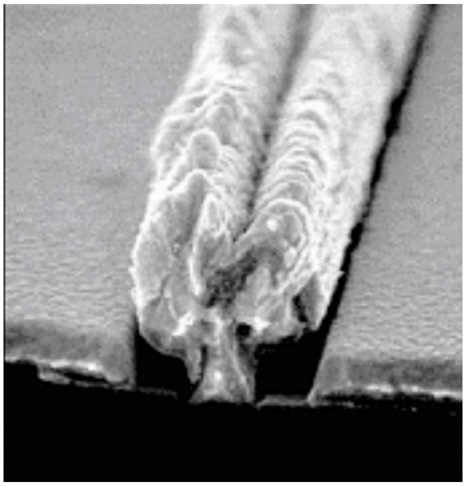


Metal T shaped structures with large heads

8.0 Electron beam lithography and Ultrafast Systems

The Ultrafast Systems Group at Glasgow has been working for many years on the design, fabrication and optimization of III-V High Electron Mobility Transistor (HEMT) and Monolithic MilliMetre-Wave Integrated Circuit (MMIC) technologies. The group works closely with other Department research groups including physics based Device Modeling and Moelecular Beam Epitaxy . The group has a number of key achievements including the fabrication of 50nm T-gate Lattice-Matched InP HEMTs with an f_T Of 430GHz using a non-annealed ohmic contact process and the fabrication of 50 nm gate length metamorphic GaAs HEMTs with a maximum transconductance of 1200 mS/mm and f_T of 300GHz .

Challenges for electron beam lithography include the optimization of pattern exposure using proximity correction, gate alignment and the optimization of processing conditions to realize reliable short gate length fabrication. As shown below, self aligned gate technology has been developed to minimize parasitic elements which limit device performance.

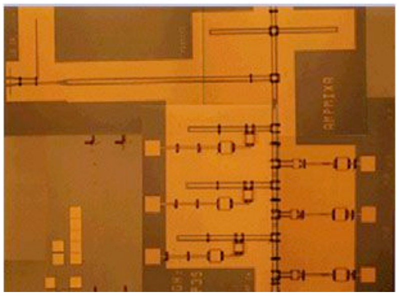


Gate fabrication using self aligned technology

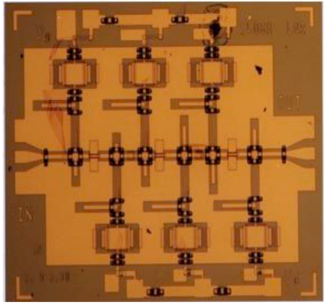
Work on III-V devices is complemented by a fully characterized library of passive components to enable the design and fabrication of monolithic millimeter wave integrated circuits. The following III-V MMICs have been fabricated at Glasgow

2.5 GHz Active Resonators
4.5 GHz Active Filters
35 GHz downconverter blocks - combined low noise amplifier / single balanced mixer
55 GHz balanced amplifier
55 GHz oscillator
77 GHz vector modulator
94 GHz low noise amplifier and oscillator
150 GHz amplifier

Two examples of circuits designed, fabricated and characterised at Glasgow



35 GHz LNA / mixer



140 GHz LNA

More recently the group has been investigating "silicon-like" process modules for III-V MOSFETs based on low damage refractory metal deposition and dry etching. For more details on ultrafast research activities see Spotlight.

9.0 Electron beam lithography – photomasks and substrates

At Glasgow considerable use is made of photolithography in micro and nanofabrication. Our large area electron beam lithography tools are used for both direct write on resist coated substrates and to produce photo mask plates with sizes up to 6 inches. We produce both light and dark field masks and have experience in a range of different types of mask plate. Photolithography is carried out mainly using Shiply S1800 series positive tone photoresists but we also make use of many other different types of positive and negative tone resist materials. Biological research activities make considerable use of very thick epoxy based resists such as SU8

Direct write electron beam lithography is carried out on a range of substrate sizes and thicknesses. We have several piece part holders for our lithography tools and we routinely pattern large numbers of substrate from around 10 mm x 10 mm to quarters of full wafers. We also routinely pattern three and four inch wafers and our VB6 UHR EWF is capable of loading 8 inch wafers.

The majority of substrates patterned are III-V materials and silicon. We have developed processing procedures for patterning insulating materials by electron beam lithography and advanced mechanical workshop activities within the university allow us to produce holder inserts for patterning unusual substrates as the need arises.

Pattern field stitching is increasingly critical for device performance particularly in optics applications. Such problems can be exacerbated by the slope of the substrate during patterning. To minimise such problems and to give improved lithography we have devised mathematical models and automatic correction methods which are applied during patterning.

To make effective use of machine patterning time and to help ensure the development of stable processing within the JWNC we routinely carry out QA procedures on key fabrication steps and this has proved extremely valuable for both research and commercial activities.