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Integrating Diamond with GaN Photonic Devices

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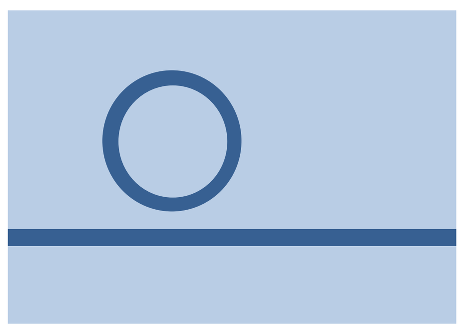
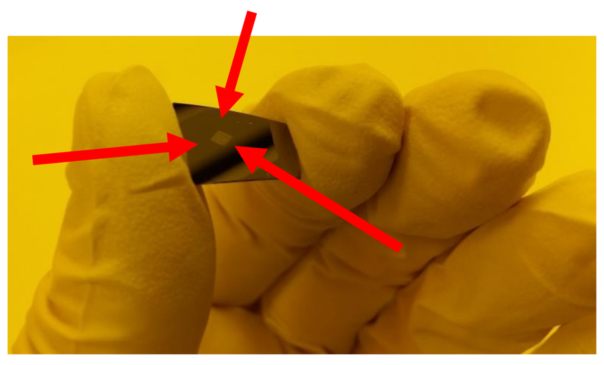
Motivation

Diamond has many defect centres. Some of these can be optically accessed for quantum applications like:

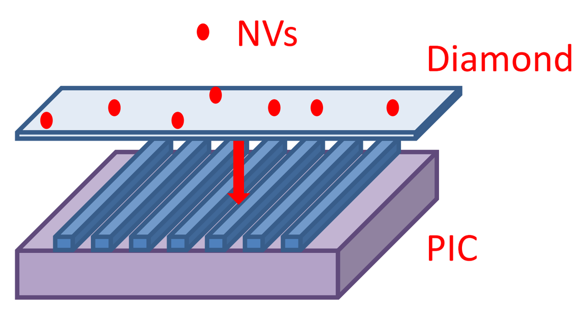
- Long lived solid state spin qubit memories (at RT)
- Quantum entanglement for cryptography & parallelisation



Example of waveguiding resonator structure (e.g. GaN)



Perspective image of diamond membrane on Si



Ultra thin diamond bonded to non native photonic device

Maximising collection of zero phonon line photon emission is of interest. Guided wave devices allow enhancement of the light-matter interaction in small mode volume devices.

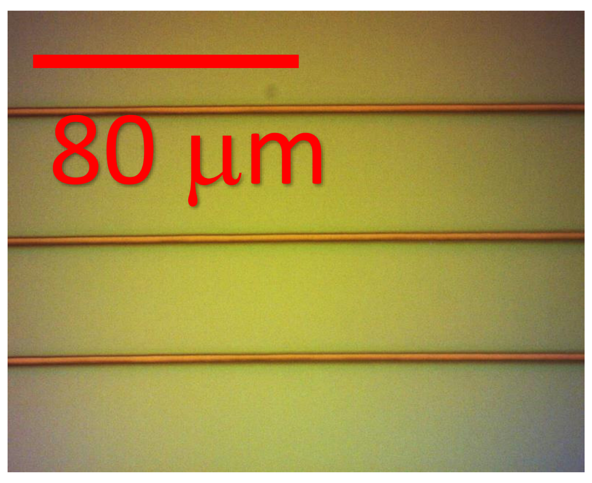
Diamond defects close to the surface of fabricated ultra-thin membranes can be coupled to these devices allowing processing of defect emissions across large area PICs.

Fabrication of GaN devices

Mode simulations were conducted to find coupling percentages between GaN devices and Diamond membranes of certain thicknesses.

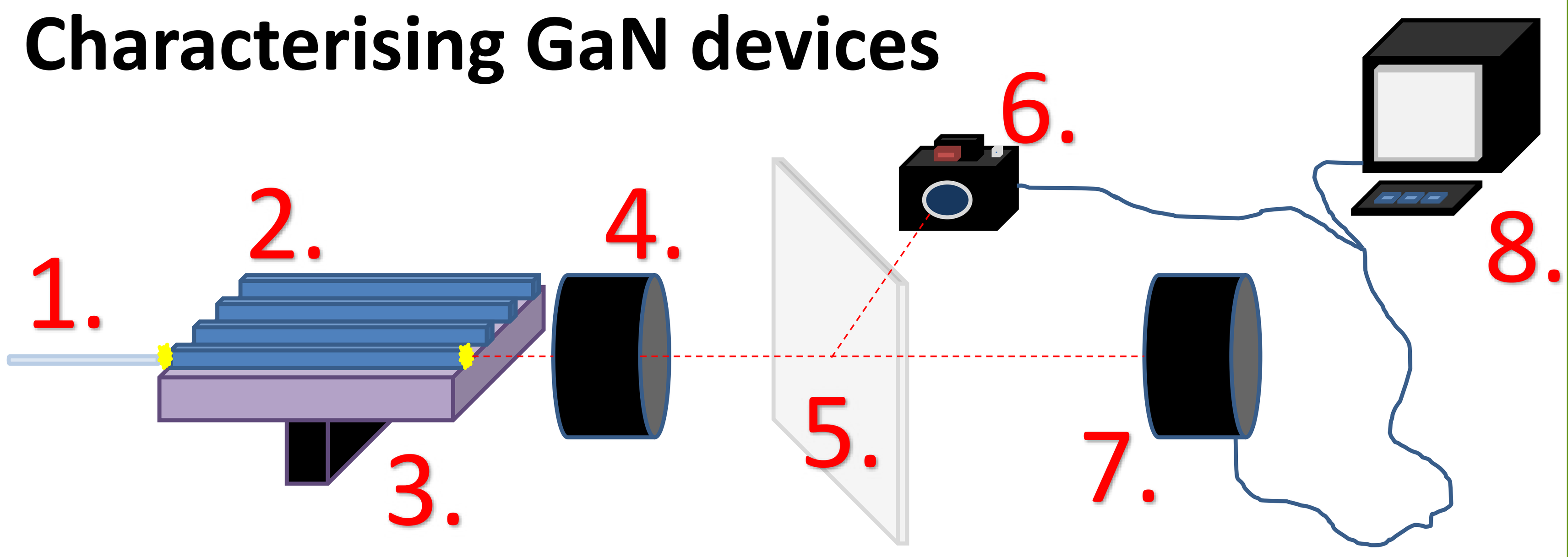
Devices were fabricated as follows:

- PECVD SiO2 masking layer (~500nm)
- Photoresist soft mask using DLW
- RIE into SiO2 hard mask
- ICP-RIE into GaN



2 micrometre wide photoresist mask guides for etching into SiO2 and subsequently GaN

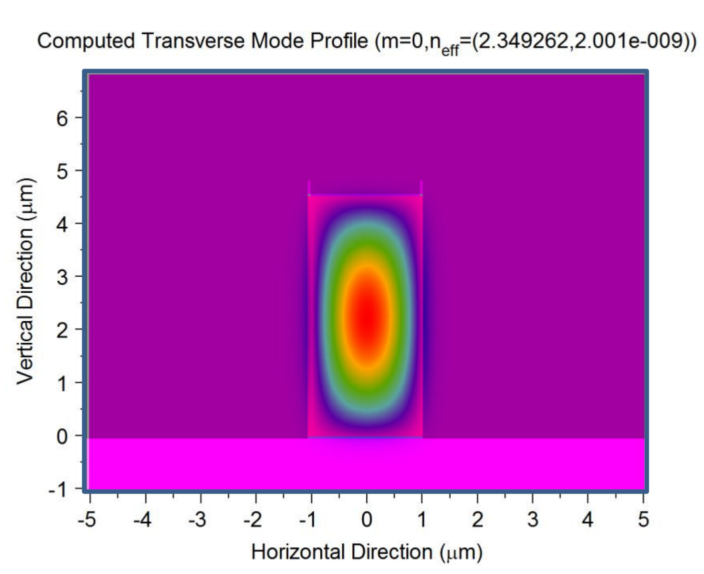
Characterising GaN devices

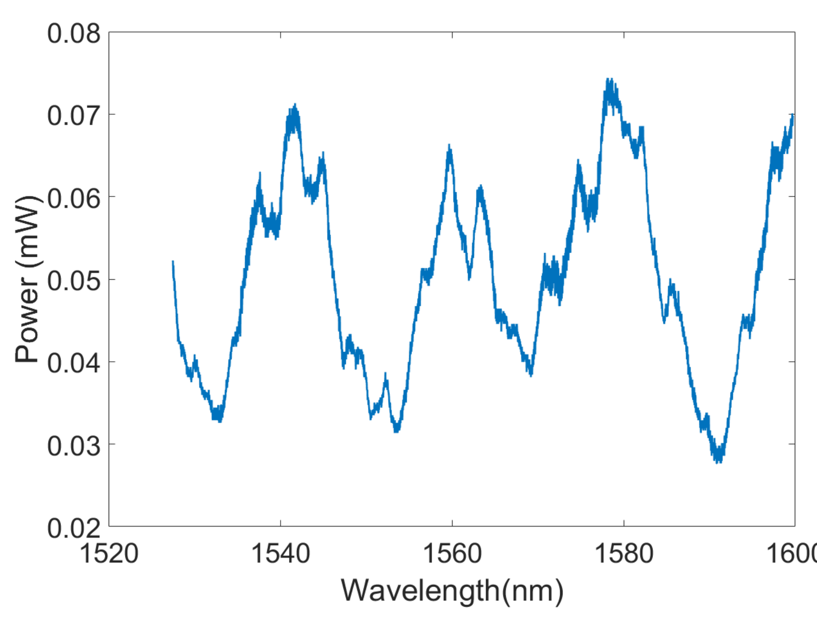


A taper-ended fibre (1) coupling through the end facet of a GaN waveguide (2)on sapphire. The sample is on a movable stage (3) and is focused with an objective (4) through a beam splitter (5) onto both a camera (6) and a power detector (7) attached to a computer (8) for signal processing.

Results of GaN waveguide device

Power readings were measured over a wavelength sweep from 1525 to 1600 nm without the sample present to measure the losses of the system.

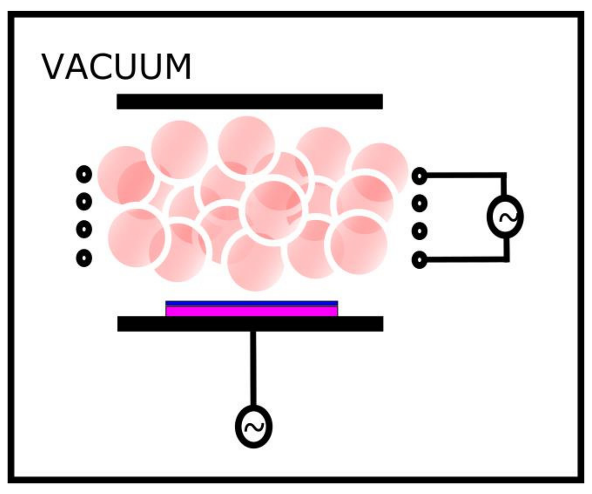




- Total TE insertion losses = -6.3 dB

The wavelength sweep is repeated with the sample in place coupled to each waveguide. A mode calculation overlaid with the waveguide geometry is shown in the figure on the left and the power detected from light coupled through a typical waveguide is shown on the right.

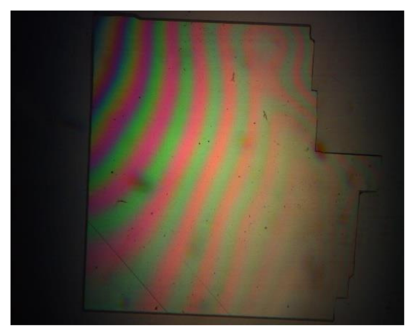
Fabrication of Ultra-thin Diamond Membranes



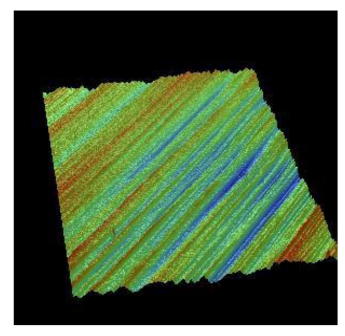
Inductively coupled plasma (ICP) etching uses an RF coil to generate a plasma above a sample on a biased platen. Changing parameters such as coil or platen power, etch speed or selectivity can be controlled.

ICP diamond etching - advantages

- Good control over anisotropy
- Non-graphitising
- Surface roughness improved
- High etch rate



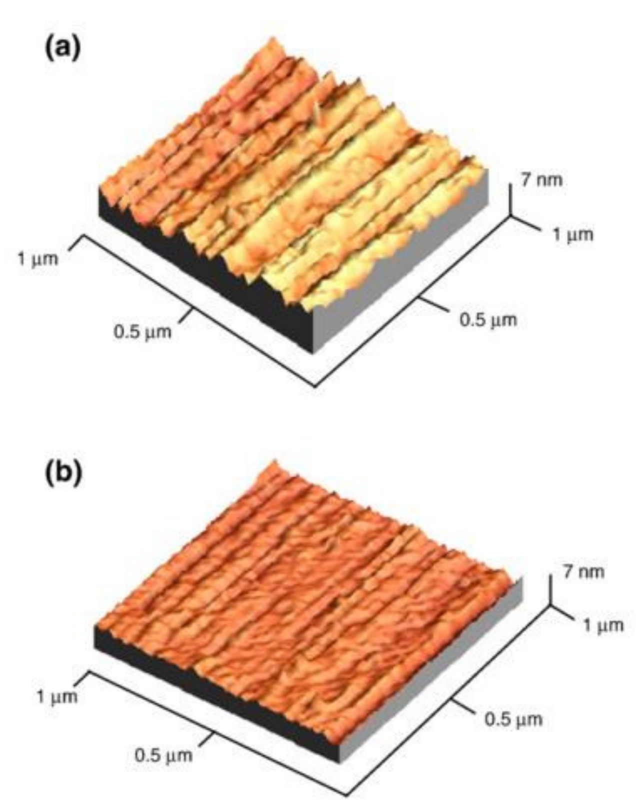
Diamond membrane part way through the thinning process



Surface roughness as measured by white light interferometer

ICP processing has been used to produce diamond,micro-lenses[1,2], waveguides[3], and raman lasers.[4]

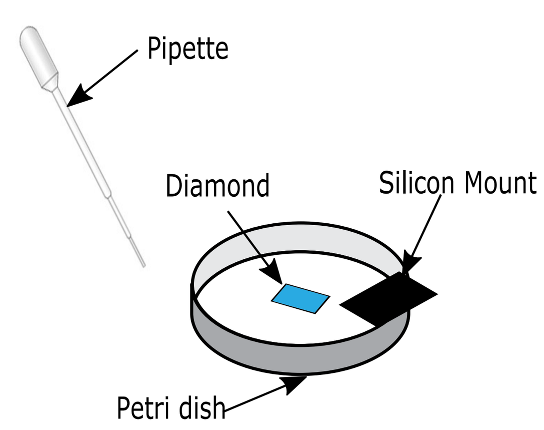
Using an Ar/Cl_2 etch recipe, diamond etches at ~60 nm/min has been shown to reduce r.m.s. surface roughness from 0.53 nm to 0.19 nm.[1]



(a) AFM image of an as received HPHT diamond and (b) the same sample after 10mins in an Ar/Cl_2 etch[1]

Handling of thin film diamond

Diamond is a low toughness material and with thinning to micron and sub-micron thicknesses, processing requires care.



Tweezers must be avoided and films moved by floating the sample onto larger handle substrates using solvent immersion and agitation via pipette.

Results

Fabrication of ultra-thin diamond membranes of **below 200 nm** have been achieved. In partnership with the NQIT project and Oxford Materials department, membranes have been bonded to a DBR mirror stack for micro-cavity enhancement of NV^- emission.[5]

Outlook

- Hybrid coupling of diamond optics to mature Photonic Integrated Circuit Technology
- Deterministic coupling of defect centres to on-chip devices
- Active control of resonator devices for wavelength tuning

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