

# Microfabrication of thin film diamond optical devices

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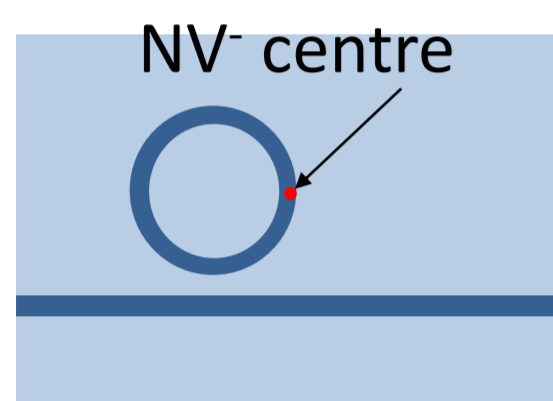
## Motivation

Diamond has many exciting applications within classical and quantum optics such as:

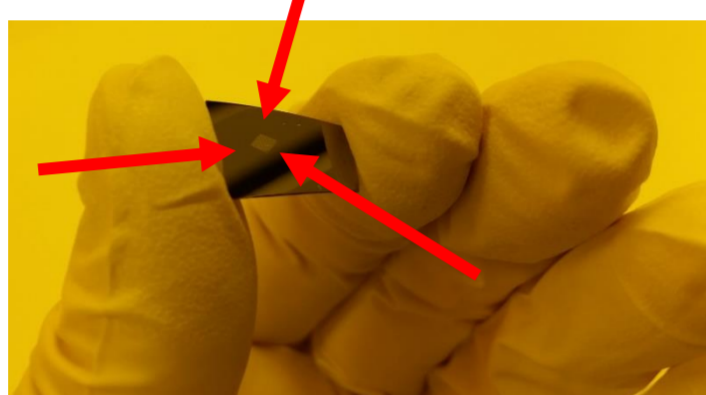
- Solid state lasers and thermal management
- Parametric non-linear optical processes
- Quantum information processing + memories
- Ultrasensitive magnetometry.

Guided wave devices allow enhancement of the light-matter interaction in small mode volume devices. Critical requirements are:

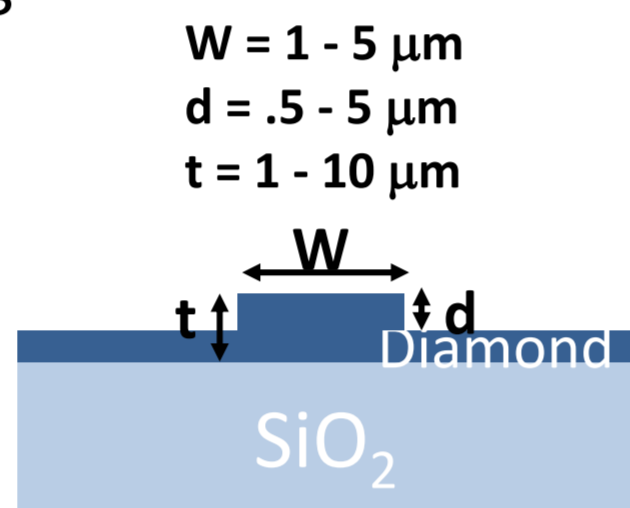
- Bulk material processing for thin film production
- Implantation for defect centre creation
- Topological processing of diamond membranes for guided wave device structures
- Low surface damage processing



20 µm diamond ring with NV-centre and coupled waveguide



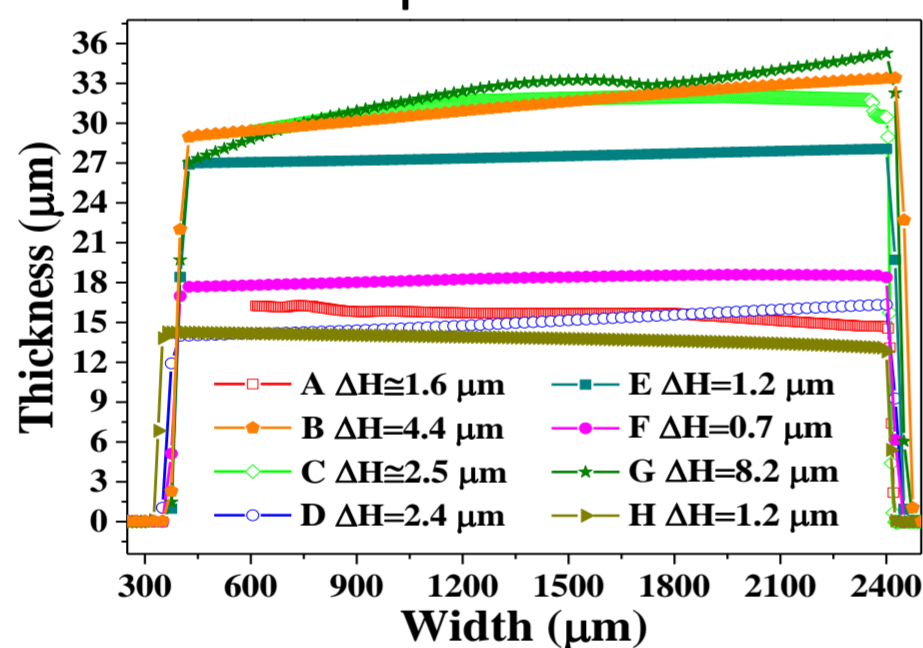
Perspective image of diamond membrane on Si



Example dimensions of diamond waveguide on silica

## Material

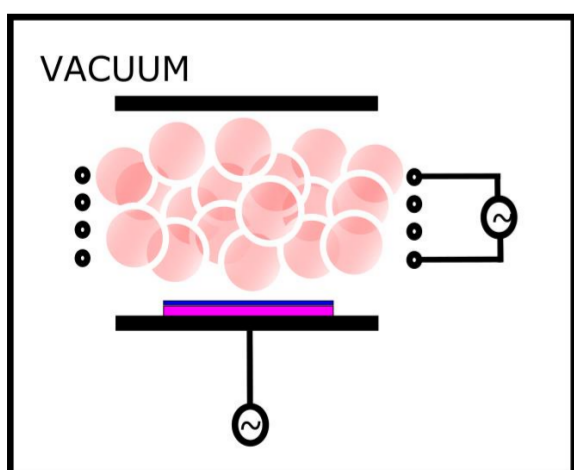
- 4x4x0.5mm CVD grown electronic-grade single crystal diamond (SCD) samples, provided by Element 6
- Bulk thinning to 20µm by Delaware Diamond Knives (DDK) for dicing into 2x2mm samples



Profilometer measurements of 8 diced and polished diamond samples showing 4 at approximately 35 µm and 4 at approximately 15 µm

- Mechanical polishing only accurate in the order of microns with surface roughness in the few nm range
- For optical devices we require film thickness ~100's nm – microns with ~1nm rms roughness

## Processing Diamond Membranes

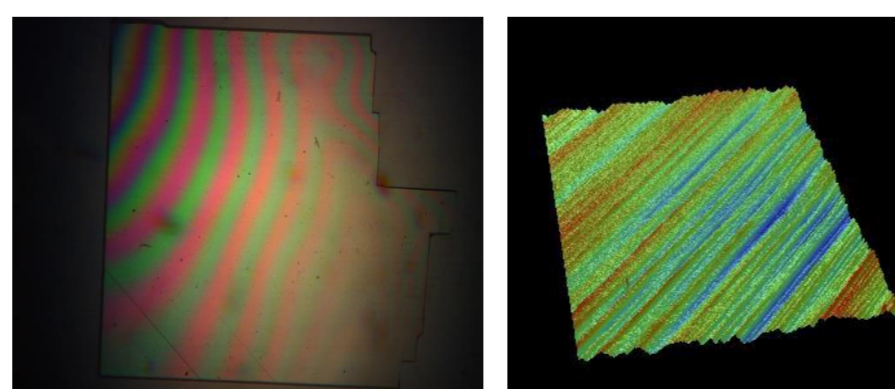


Inductively couple plasma (ICP) etching uses an RF coil to generate a plasma above a sample on a biased platen. By changing gas flow recipes to the chamber (e.g. Ar/Cl<sub>2</sub>, Ar/O<sub>2</sub>), and the bias on the coil or platen, etch speed or selectivity can be controlled.

### ICP etching

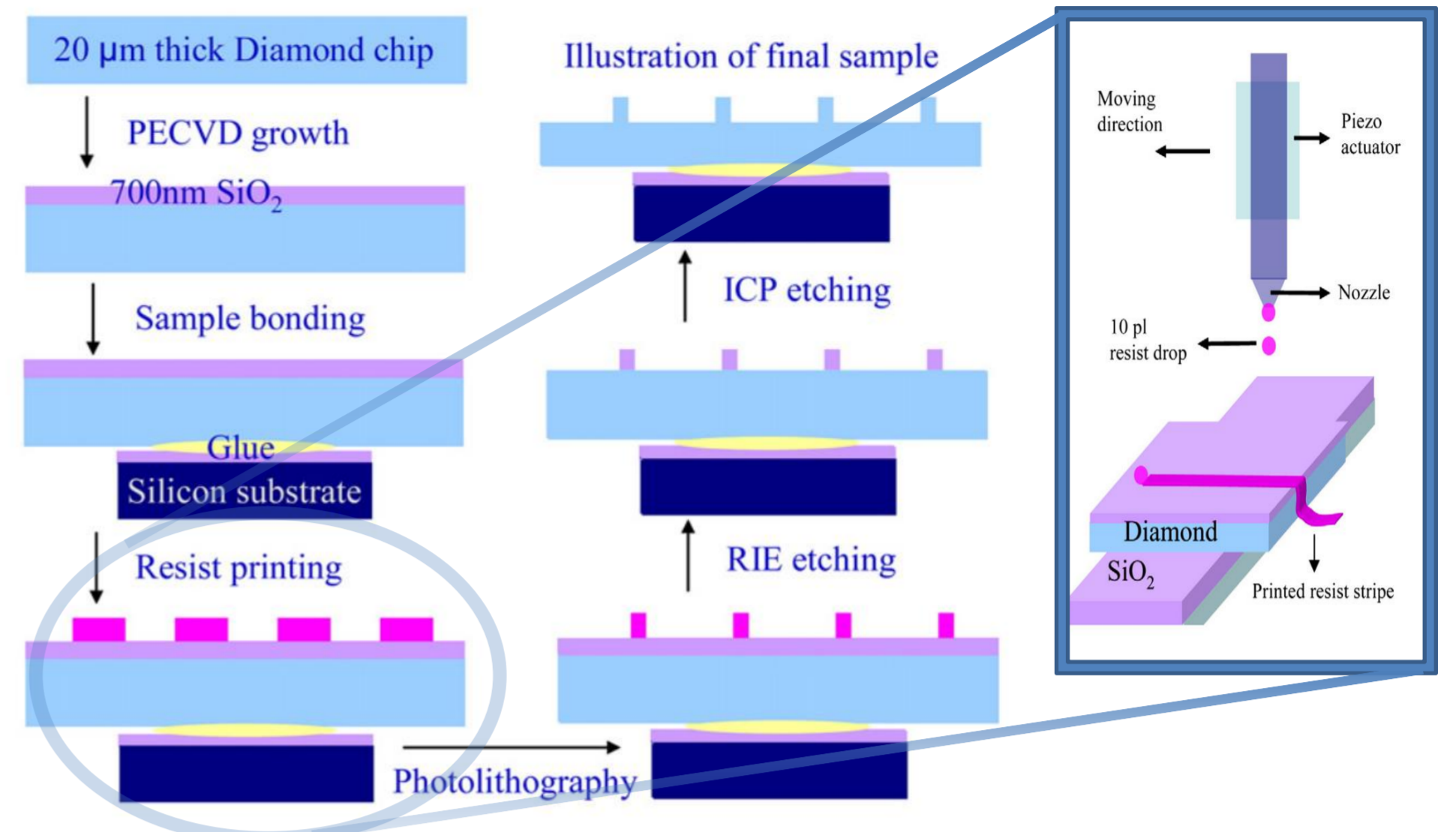
- Good control over anisotropy
- Non-graphitising
- Surface roughness improved
- High etch rate

Using an Ar/Cl<sub>2</sub> etch recipe, diamond membranes have been thinned down to below 100 nm on a DBR mirror stack for micro cavity enhancement of NV<sup>-</sup> emission.



Diamond membrane part way through the thinning process  
 Surface roughness as measured by white light interferometer

## Patterning diamond devices



Process flow for fabricating surface relief diamond optical devices.<sup>1</sup>

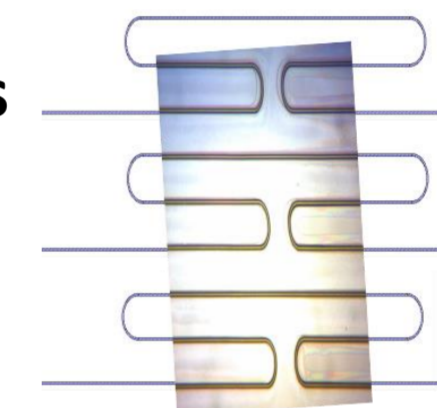
### Why print?

- Spin coating samples with photoresist results in a build up around the edge of smaller samples.
- The 2x2 mm diamond samples spin coated would result in much of the sample being coated with uneven edge effect that is difficult to pattern.
- Printing allows edge to edge resist coating

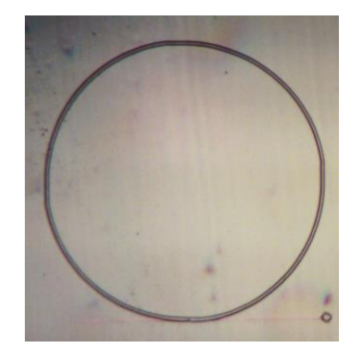
### Maskless lithography patterns



Photoresist (PR) waveguide array

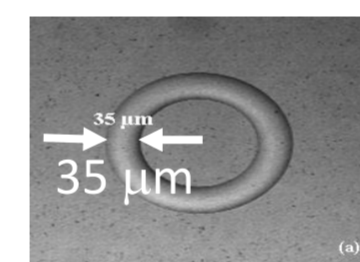


PR serpentine waveguides

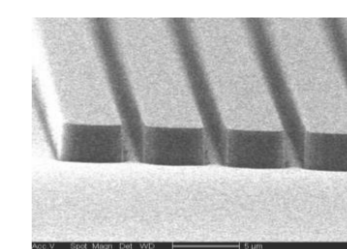


PR rings

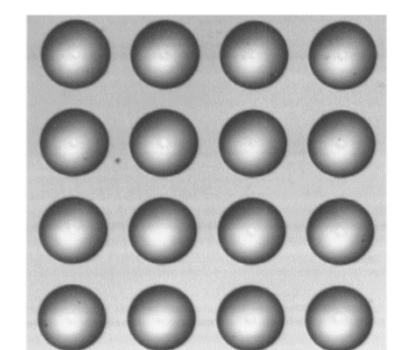
### Diamond etched features



Micro-cylindrical diamond ring<sup>2</sup>



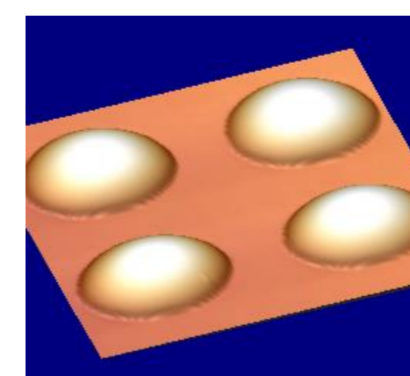
Diamond grating<sup>3</sup>



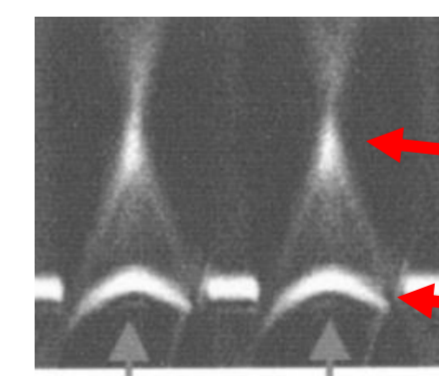
20 µm diameter diamond lenses<sup>4</sup>

## Performance of fabricated diamond optics

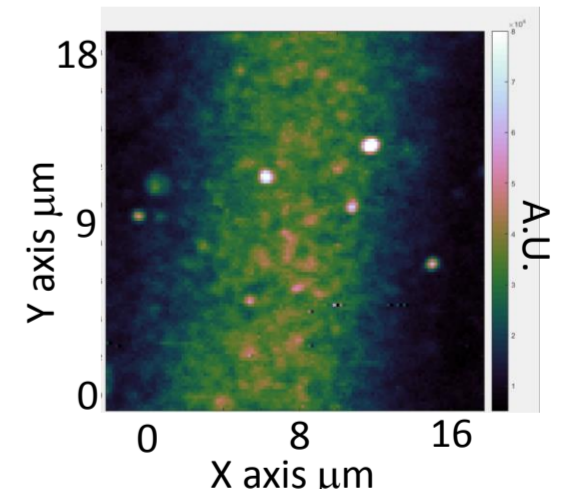
- Using photoresist reflow, spherical diamond microlenses were fabricated with focal lengths of 21 +/- 1 µm.
- NV<sup>-</sup> centre luminescence has been measured from an implanted sample etched to < 100 nm thick.



AFM profiles of spherical microlenses



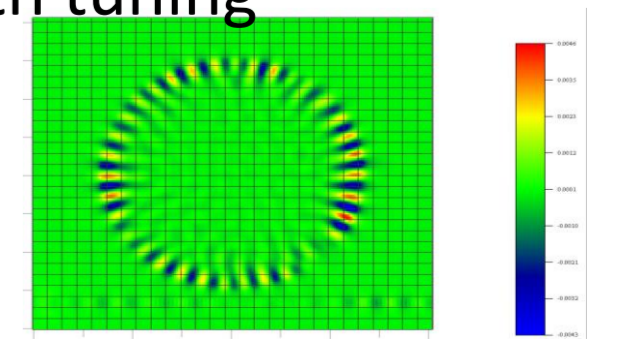
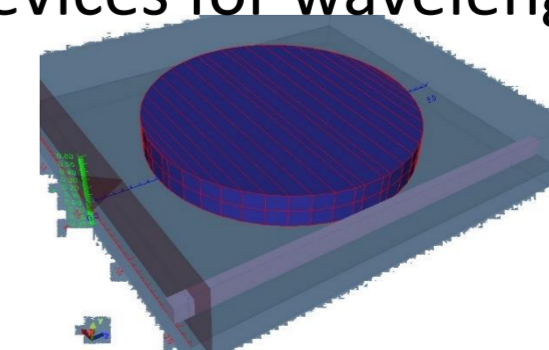
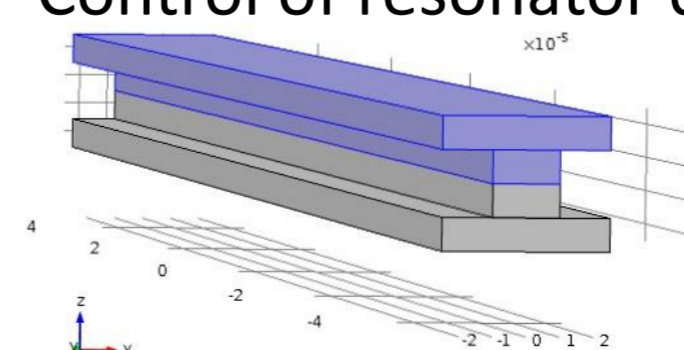
Confocal image of light directed through microlenses<sup>4</sup>



NV<sup>-</sup> fluorescence in an ultrathin diamond membrane<sup>5</sup>

## Outlook

- Hybrid coupling of diamond optics to mature Photonic Integrated Circuit Technology
- Coupling of multiple centres on-chip
- Deterministic coupling of defect centres to on-chip resonators
- Control of resonator devices for wavelength tuning



### References

1. Zhang, Y., McKnight, L., Tian, Z., Calvez, S., Gu, E., & Dawson, M. D. (2011). Large cross-section edge-coupled diamond waveguides. *Diamond and Related Materials*, 20(4), 564–567. <http://doi.org/10.1016/j.diamond.2011.03.002>
2. Lee, C. L., Gu, E., & Dawson, M. D. (2007). Micro-cylindrical and micro-ring lenses in CVD diamond. *Diamond and Related Materials*, 16(4-7 SPEC. ISS.), 944–948. <http://doi.org/10.1016/j.diamond.2006.11.027>
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5. Sam Johnstone, Jason Smith, Department of Materials, University of Oxford, unpublished.