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Microfabrication of thin film diamond optical devices

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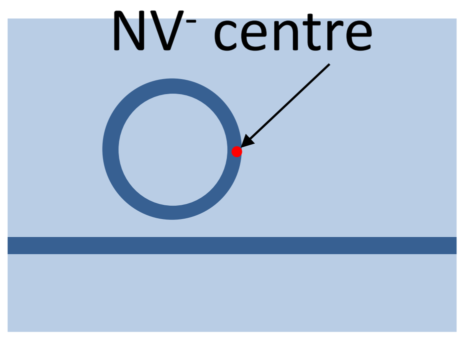
Motivation

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

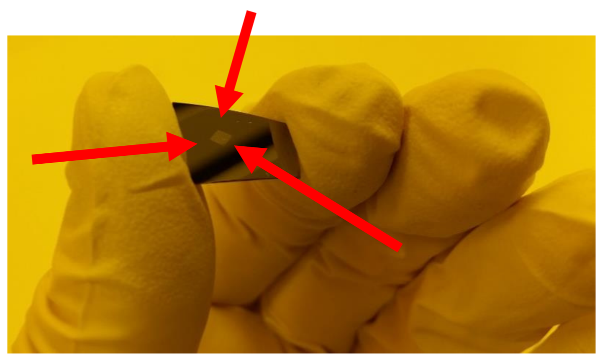
- Solid state lasers and thermal management
- Parametric non-linear optical processes
- Quantum information processing + memories
- Ultrasensitive magnetometry.

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

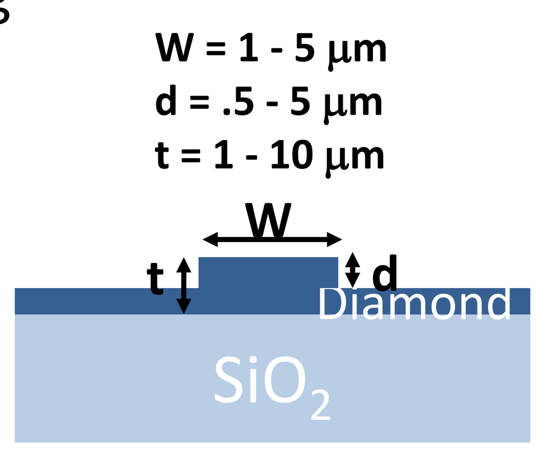
- Bulk material processing for thin film production
- Implantation for defect centre creation
- Topological processing of diamond membranes for guided wave device structures
- Low surface damage processing



20 µm diamond ring with NV^- and coupled waveguide



Perspective image of diamond membrane on Si

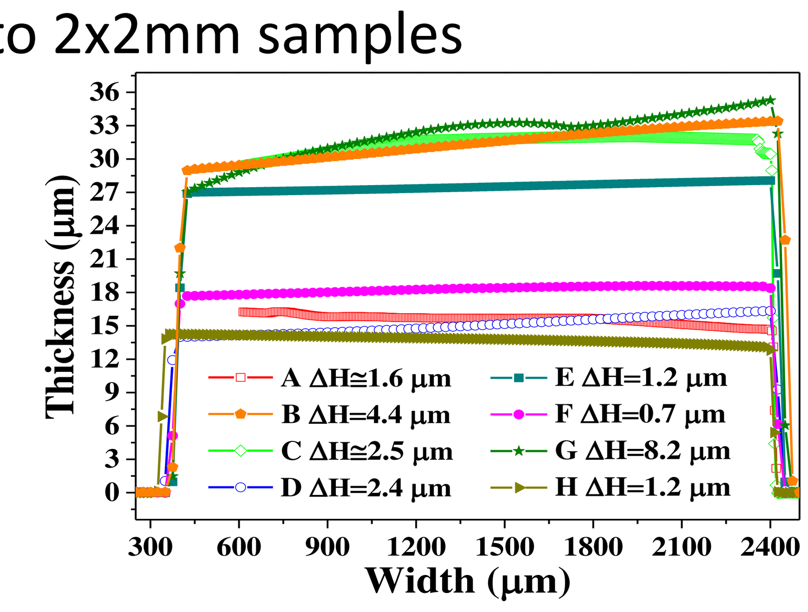


Example dimensions of diamond waveguide on silica

Material

elementsix

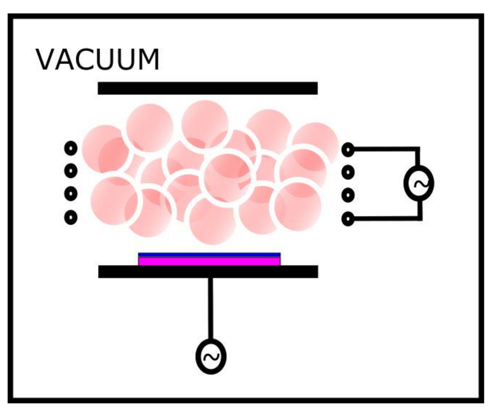
- 4x4x0.5mm CVD grown electronic-grade single crystal diamond (SCD) samples, provided by Element 6
- Bulk thinning to 20µm by Delaware Diamond Knives (DDK) for dicing into 2x2mm samples



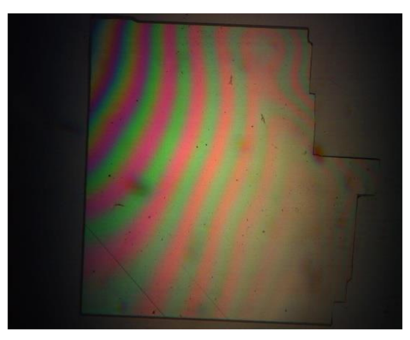
Profilometer measurements of 8 diced and polished diamond samples showing 4 at approximately 35 µm and 4 at approximately 15 µm

- 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

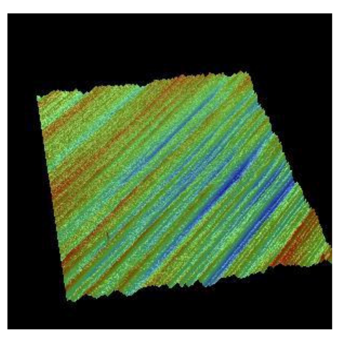
Processing Diamond Membranes



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_2, Ar/O_2), and the bias on the coil or platen, etch speed or selectivity can be controlled.



Diamond membrane part way through the thinning process



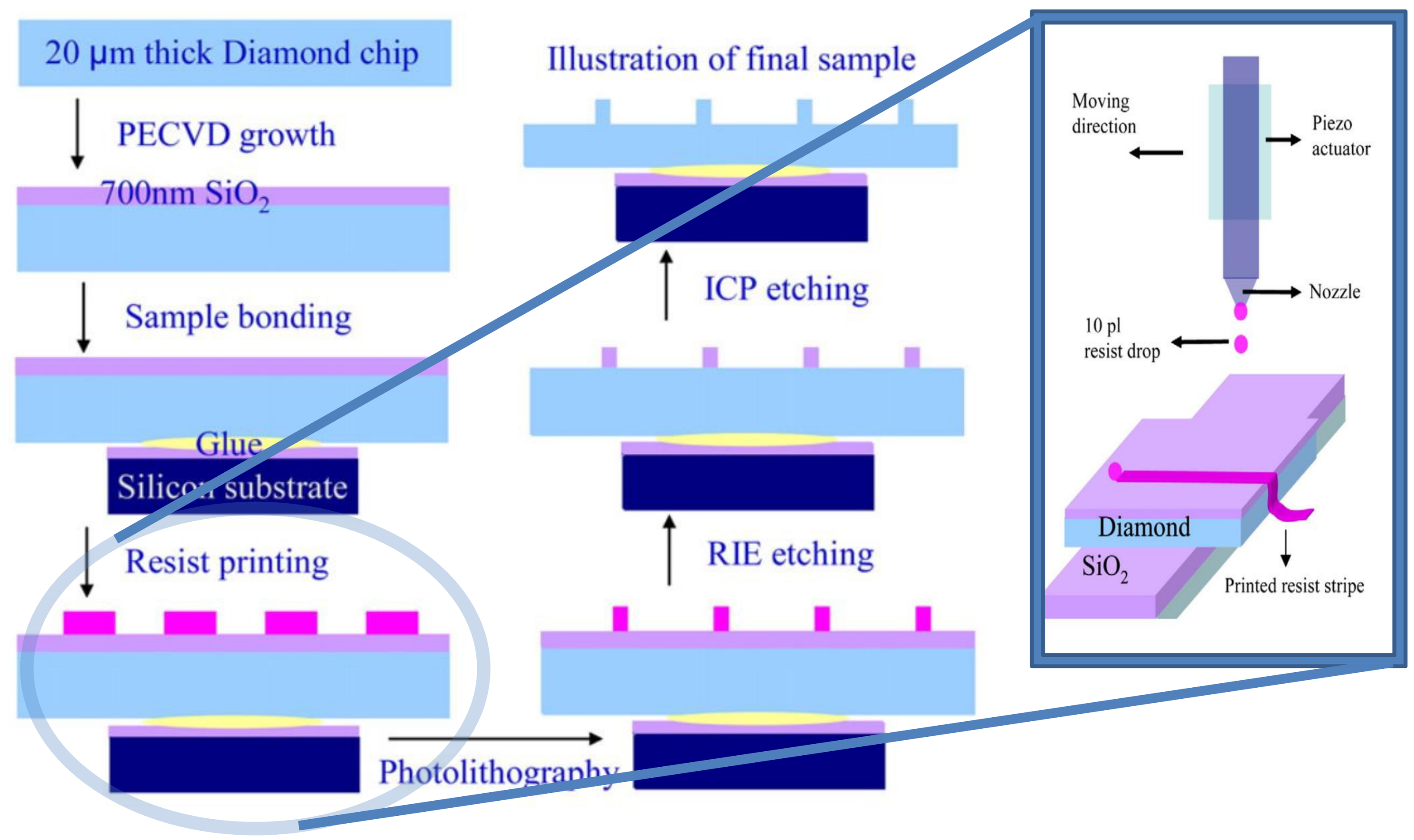
Surface roughness as measured by white light interferometer

ICP etching

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

Using an Ar/Cl_2 etch recipe, diamond membranes have been thinned down to below 100 nm on a DBR mirror stack for micro cavity enhancement of NV^- emission.

Patterning diamond devices



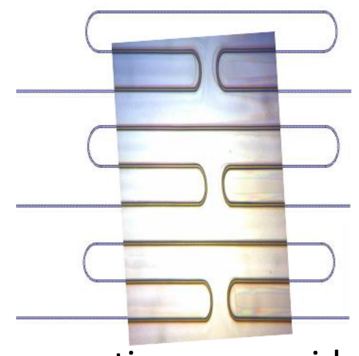
Process flow for fabricating surface relief diamond optical devices.[1]

Why print?

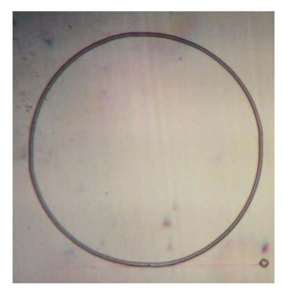
- Spin coating samples with photoresist results in a build up around the edge of smaller samples.
- The 2x2 mm diamond samples spin coated would result in much of the sample being coated with uneven edge effect that is difficult to pattern.
- Printing allows edge to edge resist coating

Maskless lithography patterns

Photoresist (PR) waveguide array

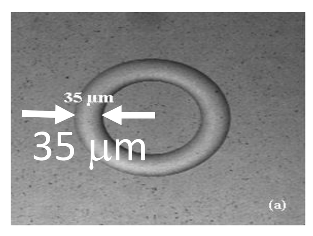


PR serpentine waveguides

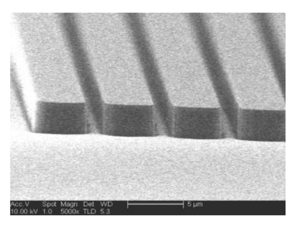


PR rings

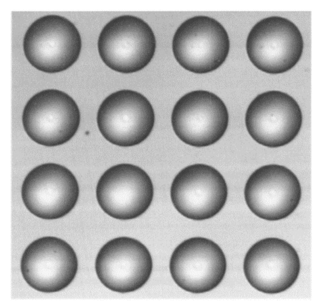
Diamond etched features



Micro-cylindrical diamond ring[2]



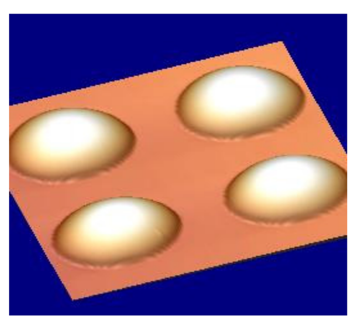
Diamond grating[3]



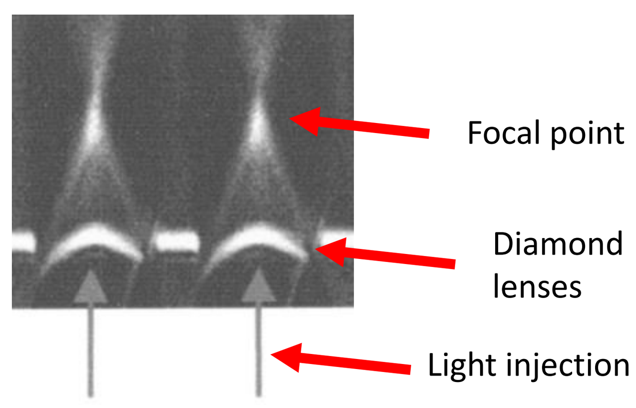
20 µm diameter diamond lenses[4]

Performance of fabricated diamond optics

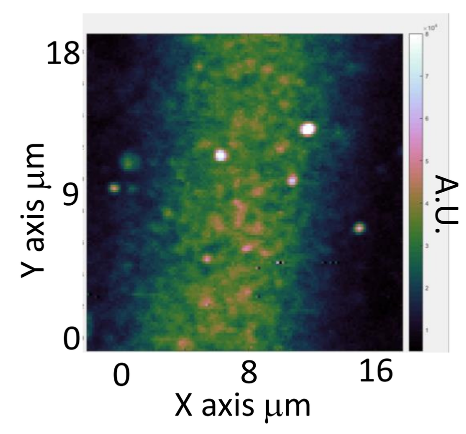
- Using photoresist reflow, spherical diamond micolenses were fabricated with focal lengths of 21 +/- 1 µm.
- NV^- centre luminescence has been measured from an implanted sample etched to < 100 nm thick.



AFM profiles of spherical microlenses



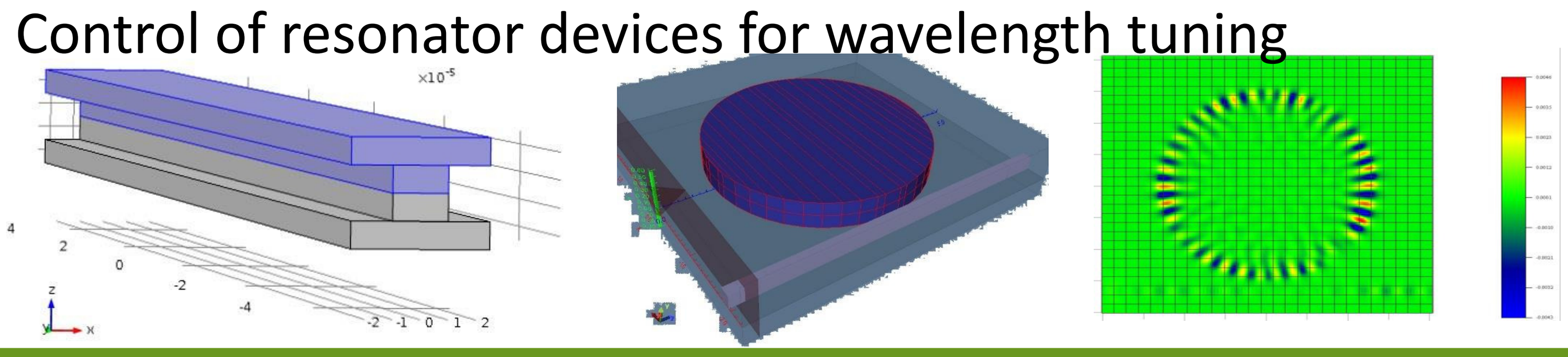
Confocal image of light directed through microlenses[4]



NV^- fluorescence in an ultrathin diamond membrane[5]

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
3. Lee, C. L., Dawson, M. D., & Gu, E. (2010). Diamond double-sided micro-lenses and reflection gratings. *Optical Materials*, *32*(9), 1123–1129. http://doi.org/10.1016/j.optmat.2010.03.013
4. Gu, E., Choi, H. W., Liu, C., Griffin, C., Girkin, J. M., Watson, I. M., … Gurney, a. M. (2004). Reflection/transmission confocal microscopy characterization of single-crystal diamond microlens arrays. *Applied Physics Letters*, *84*(15), 2754–2756. http://doi.org/10.1063/1.1695101
5. Sam Johnsone, Jason Smith, Department of Materials, University of Oxford, unpublished.