Micromachining via diamond grinding of photonic circuit facets

James C. Gates[1], Paul C. Gow[1], Glenn Churchill[1], Matthew P. D'Souza[1],
Peter G.R. Smith[1,2], Corin B.E. Gawith[1,2]

1. Optoelectronics Research Centre, University of Southampton, United Kingdom, SO17 1BJ
2. Covesion Ltd, Unit F3, Adanac Park, Southampton, SO16 0BT, United Kingdom
j.gates@soton.ac.uk

Chip-based integrated photonics is a scalable route to provide passive and active optical elements. While integrated photonics can often outperform electronic alternatives, widespread adoption is often impeded by the considerable labour time and costs involved in manufacturing, particularly during optical assembly. The lapping and polishing processes used during facet preparation are largely derived from traditional optics manufacturing. These are often challenging to automate or fail to meet the stringent positional tolerances and surface quality requirements of integrated photonic components. Although grating couplers are often employed in photonic integrated circuits (PICs), insertion loss and limited spectral bandwidth restrict their application. Therefore, the processing of the facet, the edge of the chip, is often essential for launching light in and out of the device. Foundries often use photolithographic and plasma etching to form precise facets. However, these deep reactive etching techniques often have high surface roughness, are time-consuming, increase the complexity of the fabrication process, and typically still require a die separation process.

Dicing saws are a critical tool for the separation of dies in microelectronics. They use diamond-impregnated blades and high-speed air-bearing spindles to grind wafers into dies, as shown in Figure 1. Recent work has shown that, with the correct parameters, low-surface roughness machining of brittle optical materials can be achieved with these machines. Surface roughness can be of sufficient optical quality (sub-nanometer and with low surface chipping) that optical waveguides can also be formed [1,2]. The approach replaces the need for an additional polishing process after chip singulation, providing a scalable process for the packaging of integrated photonics that can be achieved using appropriately configured commercial semiconductor dicing tools.

This talk will review our latest advances on the use of grinding tools to prepare optical quality waveguides and facets in each of the major integrated optical material platforms, including Silicon Nitride (SiN), Silicon on Insulator (SOI), Silica on Silicon (SOS), Germanium on Silicon (GOS), Lithium Niobate on Insulator (LNOI), tantalum pentoxide on silica, and more specialist materials such as $GeTe_4$, and chalcogenides [2-6]. Figure 2 shows scanning electron microscope images of machined channel waveguides and facets; Figure 2(a) shows a SiN on an insulator waveguide with a side wall roughness of 1.5 nm (Sa), and Fig. 2(b) an indiffused lithium niobate waveguide with a side wall roughness of 0.3 nm (Sa). Figure 3(a) shows an optical microscope image of the top surface of the SiN waveguide, showing the ability to produce chip-free edges and no delamination of the waveguide film. Figure 3(b) shows a plot of one of the key parameters – machining feed rate, showing the transition from ductile (low roughness) to brittle (high roughness) material removal. SiN and LN represent the extremes of the material hardness scale and the underlying physical ductile grinding process, which produces chip-free optical-quality surfaces, and critical process parameters to achieve sub-nm roughness features in these materials will be discussed.

As an example application, we will also present our work on the formation of lithium niobate waveguides for parametric optical wavelength conversion, where form (waveguide uniformity) is as critical as the optical surface roughness. Finally, we will include our most recent results on the development of an in-house built ultra-precision dicing system with nanometer resolution, which we will use as a test bed for optimising the grinding process and allowing the process to be used in other areas of microelectronics and photonics.

[1] Ito, Hiromasa, et al., Conference on Lasers and Electro-Optics. Optica Publishing Group, 2005.
[2] Carpenter, Lewis G., et al., Optics Express 28.15 (2020): 21382-21390.
[3] Gow, Paul C., et al., Electronics Letters 60.5 (2024): e13138.
[4] Ettabib, Mohamed A., et al., Plos one 18.8 (2023): e0284058.
[5] Vitali, Valerio, et al., Photonics Research 11.7 (2023): 1275-1283
[6] Mittal, Vinita, et al., Optics Letters 40.9 (2015): 2016-2019.
[7] Carpenter, Lewis G., et al., Journal of Physics D: Applied Physics 46.47 (2013): 475103.

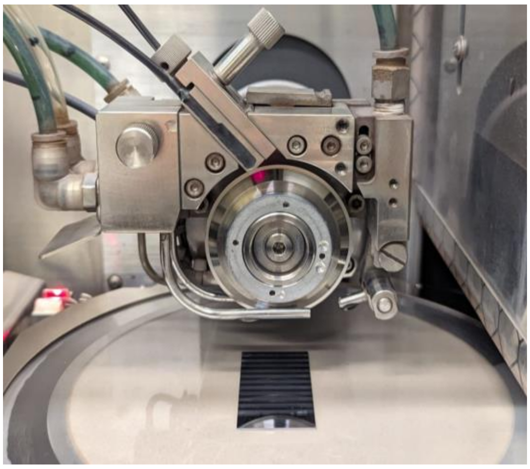

Figure 1. The commercial dicing machine (Disco DAD 3430) used in much of the presented work. It provides sufficient precision to achieve ductile machining of optical materials.

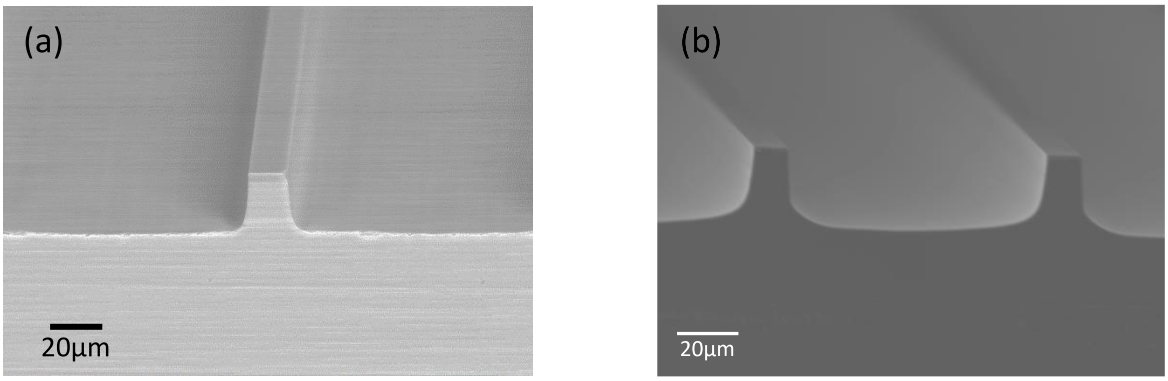

Figure 2. Scanning Electron Microscope images of waveguides (lateral confinement) and facets produced via precision dicing with diamond blades. **(a)** Silicon Nitride (SiN) on silica with a surface roughness of 1.5nm (Sa). **(b)** periodically poled lithium niobate indiffused waveguide with 0.3 nm surface roughness (Sa).

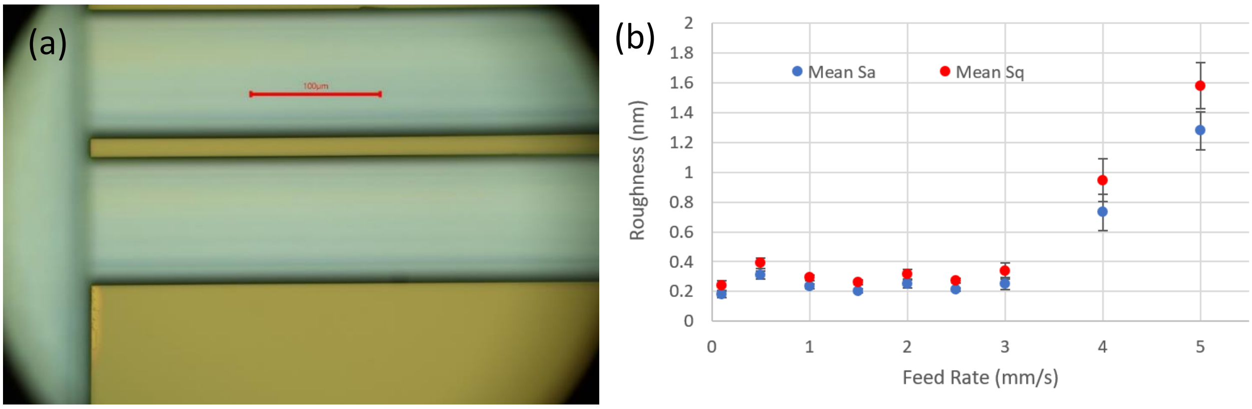

Figure 3. (a) Microscope image of the top surface of the SiN waveguide shown in Fig 2(a), illustrating the chip-free surface of the machining. **(b)** Data showing the effect of feed rate on the side wall surface roughness of lithium niobate.