Direct Bonding Nd:YAG to Sapphire Wafers
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Abstract: We demonstrate chemical and plasma-assisted direct bonding of 490µm-thick 1.9at. % neodymium-doped YAG to 660µm-thick sapphire wafers. Bonded composites survive extreme environments as well as abrasive mechanical processing. Diced, polished and AR-coated, the composite was trialled in a pump-guided free-space laser.

Motivation
- Investigate & develop a repeatable and resilient bonding procedure
- Join dissimilar crystals, such as YAG and Sapphire, to make a composite structure
- Demonstrate bond resistance to temperatures, physical environments and mechanical processing
- Produce an active device to show heatsinking capabilities of bonded devices

1. Why direct bonding?
- Direct bonding offers a ‘universal’ technique capable of joining a wide range of materials with no intermediate layer
- Direct bonding has been demonstrated between various materials including glasses, crystals, metals and plastics, which enable joining of similar or dissimilar materials
- Sapphire’s high thermal conductivity is twice that of Nd:YAG. A thin, heat-spread layer of sapphire can be joined to an active Nd:YAG layer for use in high-power operation.

2. Surface finish and bond activation
- Direct bonding relies on short-range van der Waals forces, requiring intimate, nanometre separation
- Faces to be bonded require strict polishing to minimise roughness and maximised flatness
- Both 400µm and 0.49mm thick μm Nd:YAG samples were bonded to 0.66mm thick sapphire wafers

3. Developing a resilient bond
- The bond is strengthened through extended (50hr), high-temperature (80°C) annealing
- As temperature increases, hydroxyl groups dissociate from the surface, transferring the transient hydrogen and σ-bond bonds to rigid covalent bonds
- Bond strength is increased to survive submersion, ultrasonic treatment, dicing and cryogenic cooling

4. Environmental testing
- Imperfectly bonded composites were tested in a series of environmental trials. Ultrasonic solvent submersion as well as elevated temperatures produced no change to the bonds, showing strong resilience
- A YAG to sapphire bond which showed interference patterns in certain regions was cooled in a vacuum chamber to -48°C and left for several days. Despite these regions being potential failure points, no change was noted in the bond interface

5. 869nm pumped 1.064µm laser
- The sapphire layer was soldered to a liquid-cooled copper heatsink
- Planar structure guides the slow-axis of the diode pump laser beam, with free-space propagation for the other. The pump was focussed to 390µm x 1mm, with slow axis waist positioned at the facet
- Laser cavity optimised for a 145 micron mode radius in the composite
- Laser performance was characterised with and without pinhole to isolate the diffraction-limited portion
- Slope efficiencies recorded showed that 34% of the power was diffraeted out from the fundamental mode
- This was believed to be due to warped end facets of the YAG leading to diffraction losses, which also limited the laser performance
- 3D surface profiles were recorded across the coated end facets showing clear aberrations across the surface of F-V 490µm. This was present on both end facets
- This would distort the beam during multiple cavity trips, resulting in power diffracted outward
- Stricter polishing standards are required for both end facets before coating for laser experiments

6. Summary
- We have successfully bonded Nd:YAG and sapphire using both wet chemical and plasma activation.
- The bonded composites were tested in a variety of environments, surviving temperature extremes and abrasive mechanical processing
- A diced and polished composite was built into a diode-pumped laser oscillator
- No evidence of damage observed for an incident irradiance of 6.75kW/cm², or thermal loading density of 475kW/cm³

References