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High-brightness Yb:YAG planar waveguide laser with an unstable resonator formed with a novel laser-machined, toroidal mode-selective mirror

Ian J Thomson, Krystian L Wlodarczyk, Denis R Hall and Howard J Baker

School of Engineering and Physical Science and the James Watt Institute, Heriot-Watt University, Edinburgh, UK

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James Watt Institute for High Value Manufacturing

Introduction

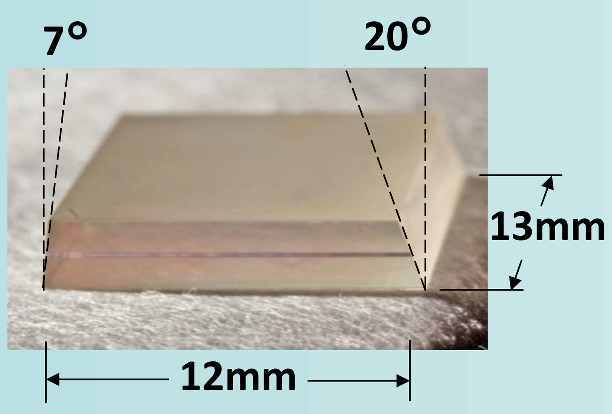
Previously (1), we have shown that a large core height Yb:YAG planar waveguide section can be efficiently core-pumped by diode bar stacks. The gain section was tested in a variety of external cavities. In multimode operation, it produced 400W cw output and 75% internal slope efficiency. The work showed that issues such as matching many diode bars into the 150 micron core height and suppression of internal parasitic oscillation have been successfully dealt with, and a gain coefficient of 1 m^{-1} achieved for MOPA applications (2). However, there remains the requirement for improvement of the beam quality of the hybrid unstable /waveguide resonator which is the preferred method for extracting oscillator power from the large aspect ratio gain cross-section.

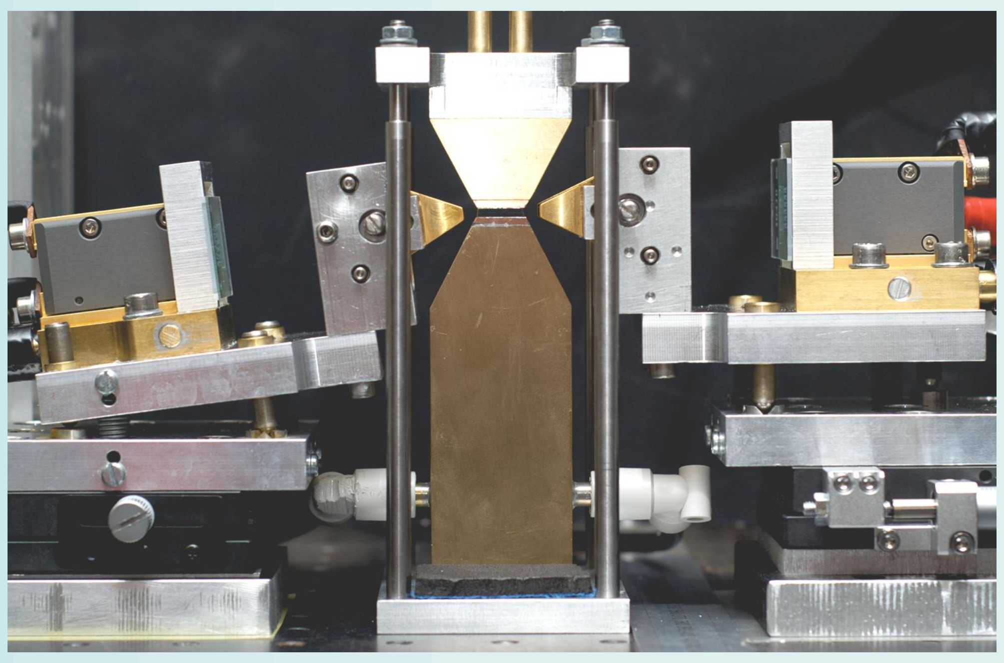
Ideally, such a resonator should use just two mirrors, and provide mode selection in the narrow, waveguide direction. In this poster, we describe the development of a novel fabrication method for micro-stripe toroidal mirrors using CO_2 laser machining of silica. We show that the use of this highly mode selective end mirror solves previous problems of interference between core and cladding light found with simple spherical mirror unstable resonators. An output of 326 W is obtained in a single spot elliptical mode, with M^2 <1.5

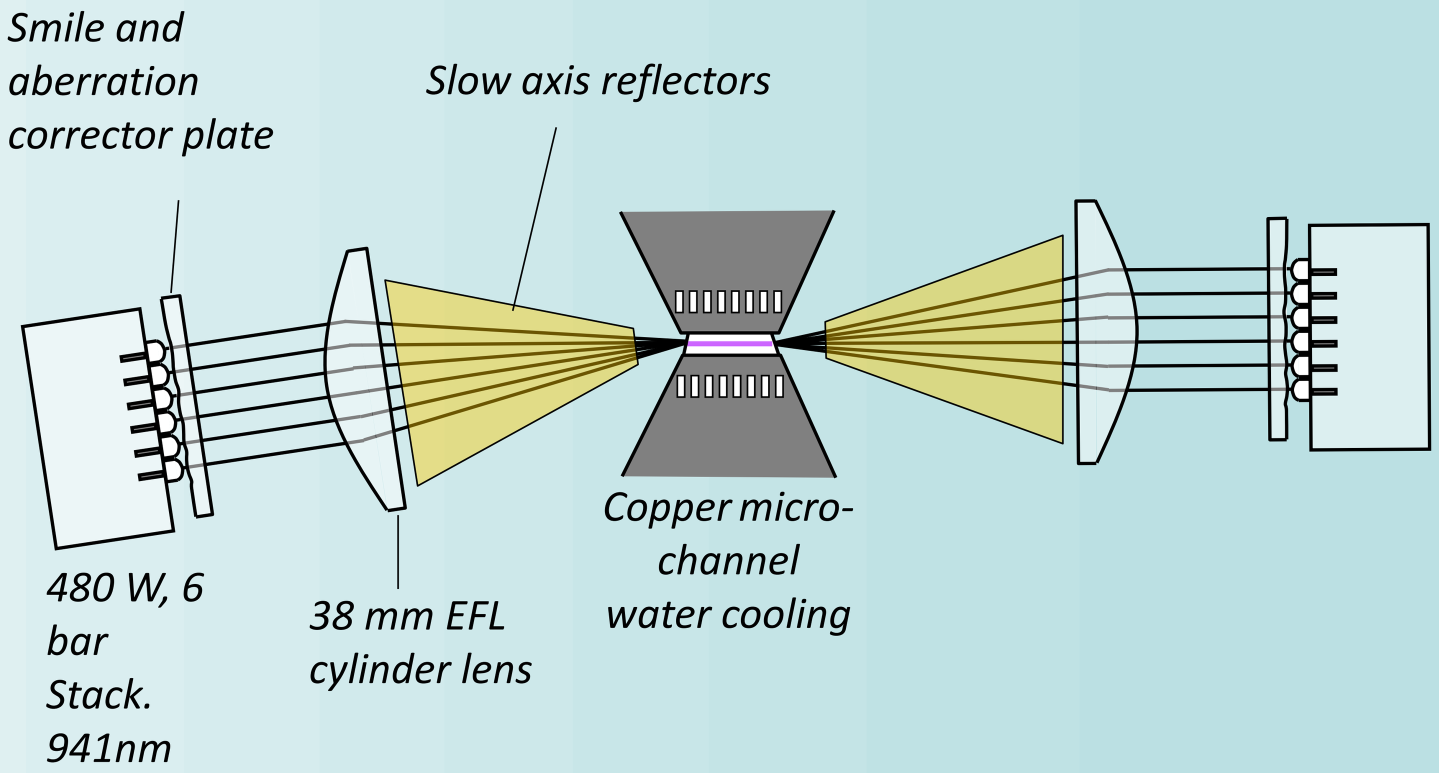
(1) I J Thomson, JF Monjardin, HJ Baker, DR Hall IEEE JQE **47**, 1336 (2011) "Efficient Operation of a 400 W Diode Side-Pumped Yb:YAG Planar Waveguide Laser"
(2) C Y Ramerez-Corral, I J Thomson, C G Leburn, D R Hall, D Reid, H J Baker. ASSP 2012 paper AT3A.5

Amplifier module

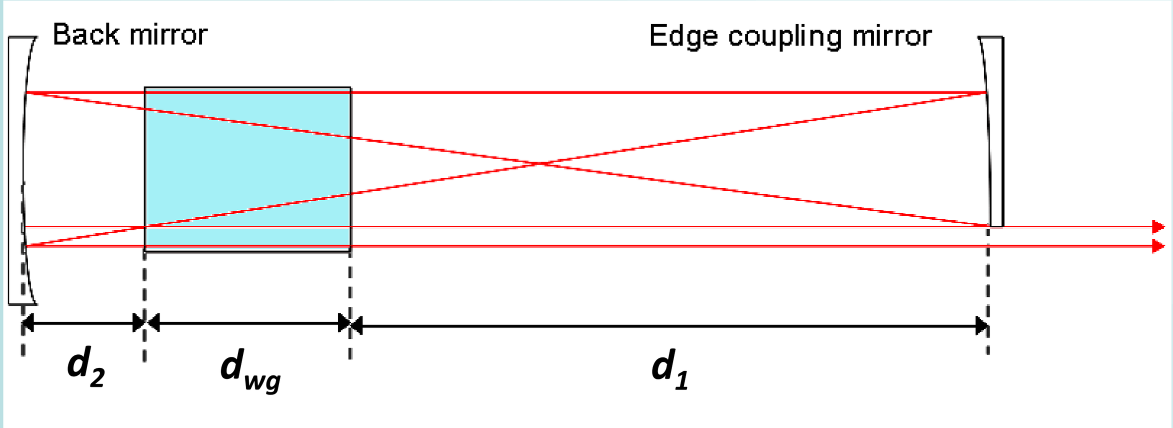
Composite YAG /Sapphire slab
Core 150 micron, 2 at.% Yb doping
(Onyx Optics)







Negative branch confocal hybrid resonator using spherical mirrors

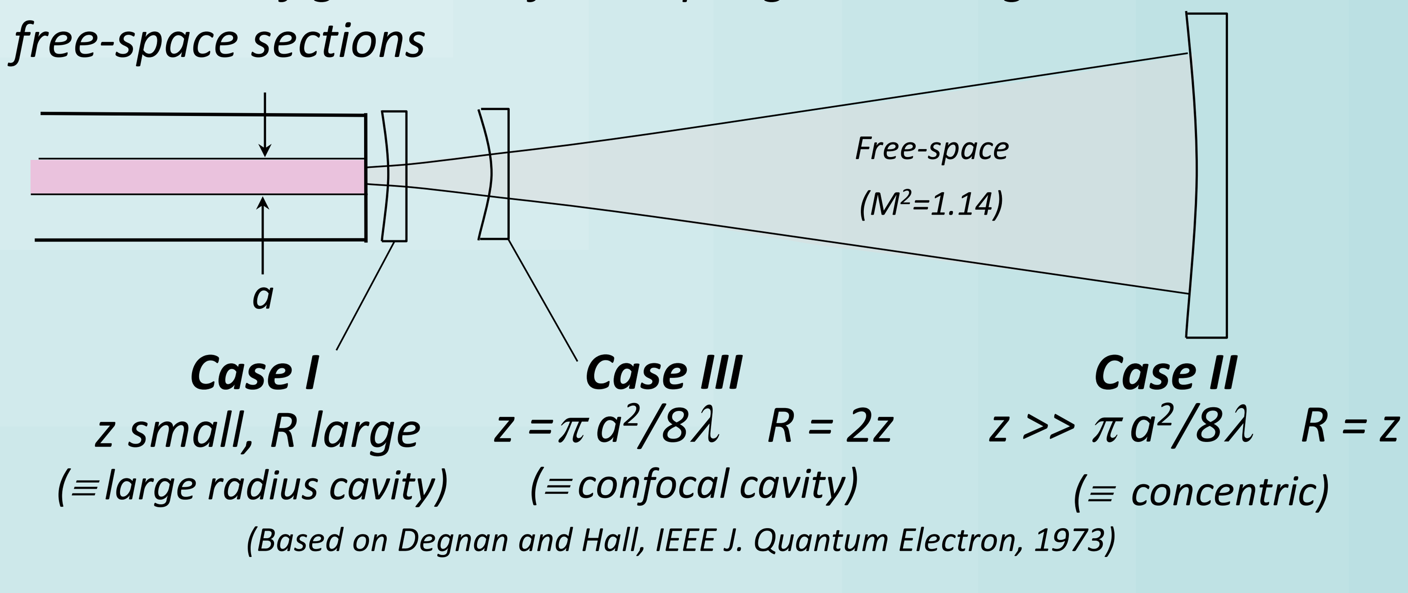


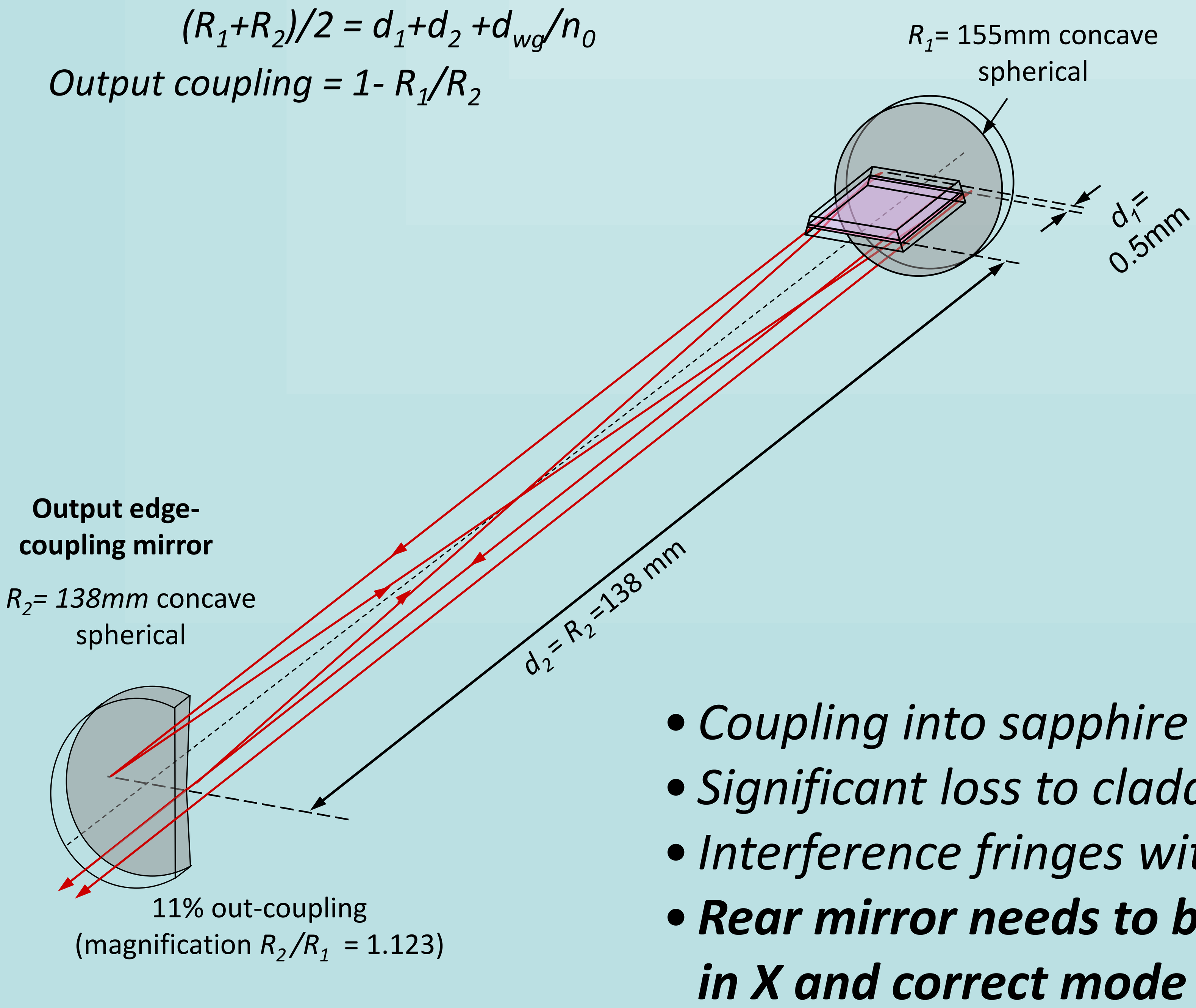
Confocal condition (parallel output beam)

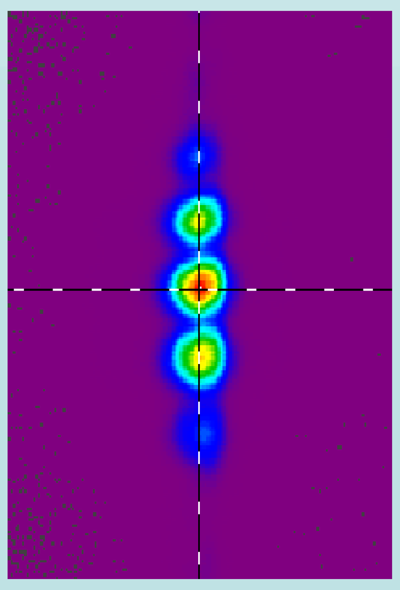
$(R_1+R_2)/2 = d_1+d_2+d_{wg}/n_0$

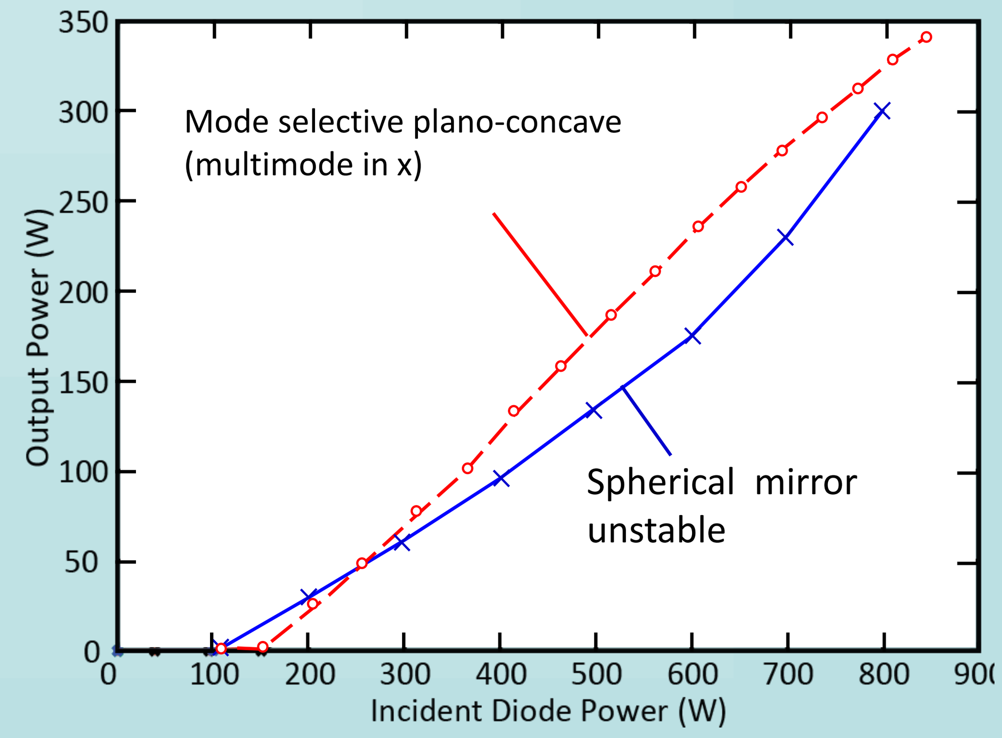
Output coupling $= 1- R_1/R_2$

Low loss configurations for coupling between guided and free-space sections









- *Coupling into sapphire claddings by non-optimum rear mirror RoC*
- *Significant loss to claddings*
- *Interference fringes with high contrast superimposed on y direction far-field*
- ***Rear mirror needs to be toroidal to satisfy both the confocal UR requirement in X and correct mode matching to the active core only in Y***

Laser Machining Of Toroidal Mirrors

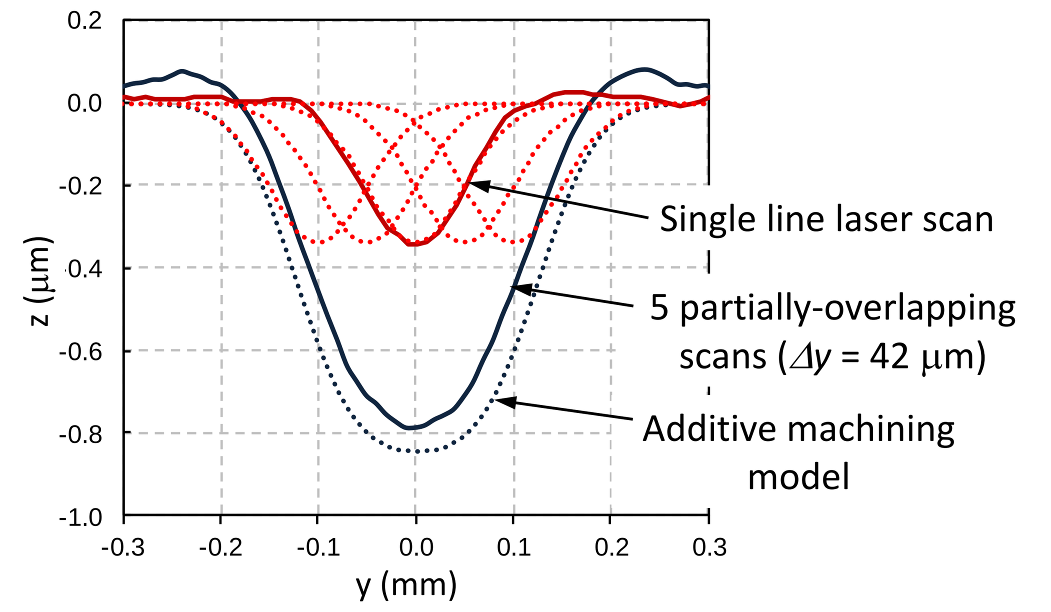
Method

- Smooth evaporation of silica by linear scanning of CW beam, 5 mm/sec
- 10.6μm wavelength CO_2 laser, with power of 8 to 9 W
- Active laser power stabiliser, ~1%
- 1 mm diameter on silica surface
- Evaporation on the 100 nm depth scale in a 200 μm melt track width
- Trench generated to match mirror requirements by multi-pass treatment

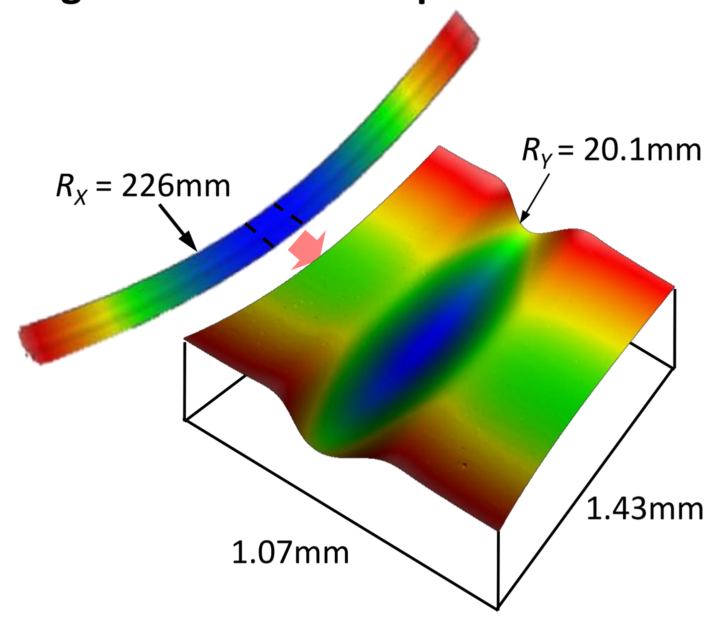
Machining on cylindrical substrates

- Conventionally ground and polished UV grade silica cylindrical lenses used as mirror substrates
- Negative branch confocal UR needs typically R_x=200 mm with sag of 0.3 mm at centre.
- Rayleigh range of CO_2 laser beam >> sag, so uniform width is obtained without focus adjustment.

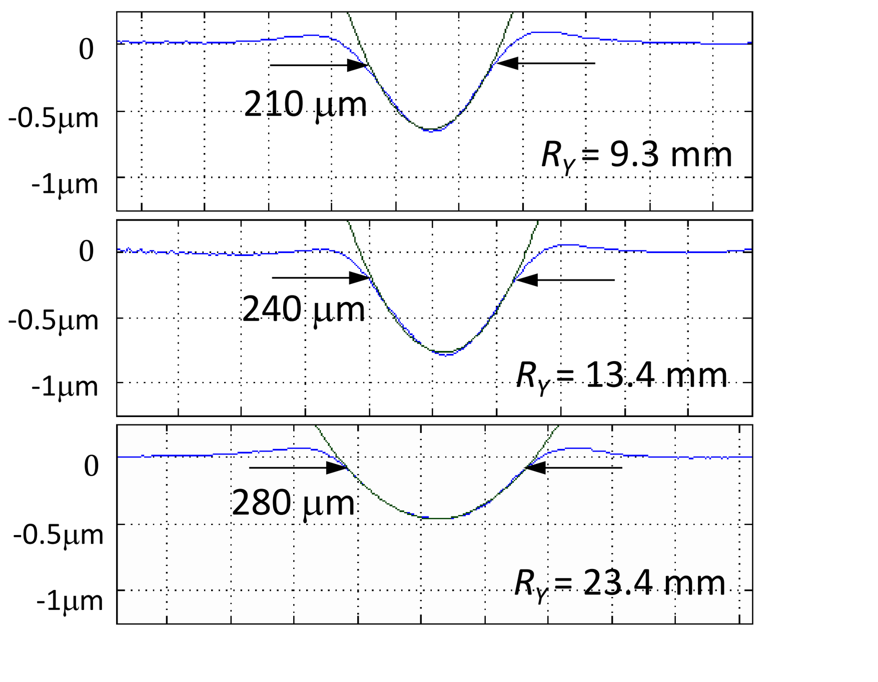
Generation of desired width and RoC



White light interferometer profile of toroidal section



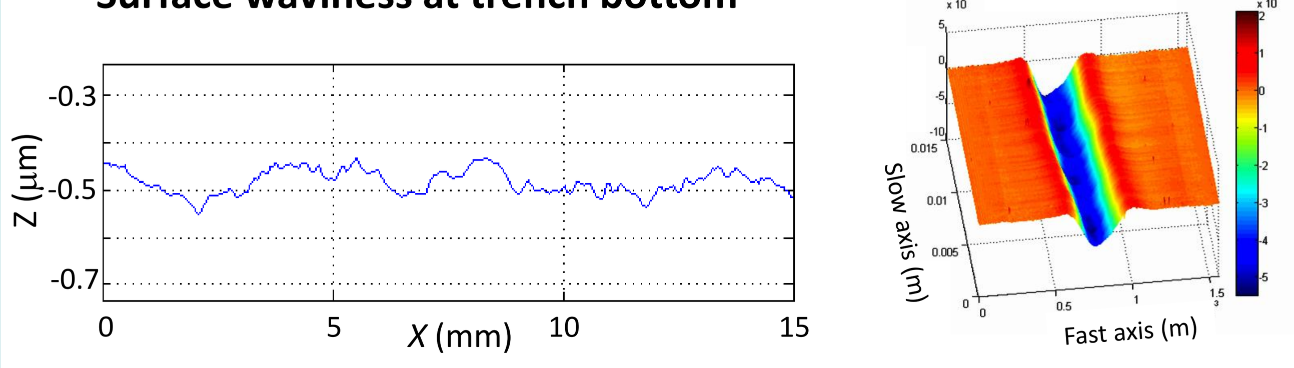
RoC in the region for Case III mode matching



Summary

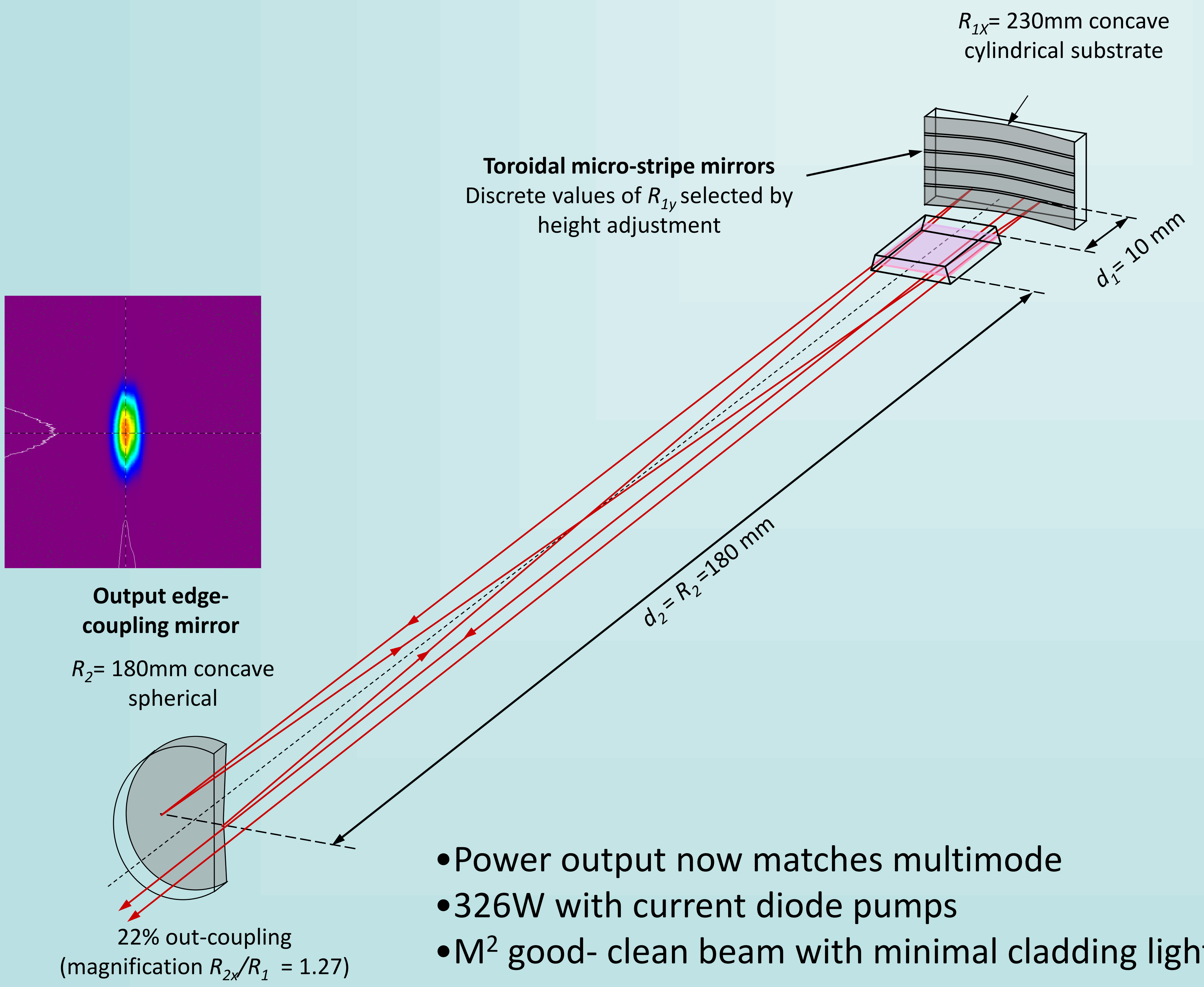
- Process produces custom microstripe toroidal mirrors
- Mirrors can be matched in both stripe width and RoC to optimise mode matching and reject higher order modes
- λ/5 wavefront errors
- Mirror quality is sufficient for use with UR which tolerates long period waviness

Surface waviness at trench bottom

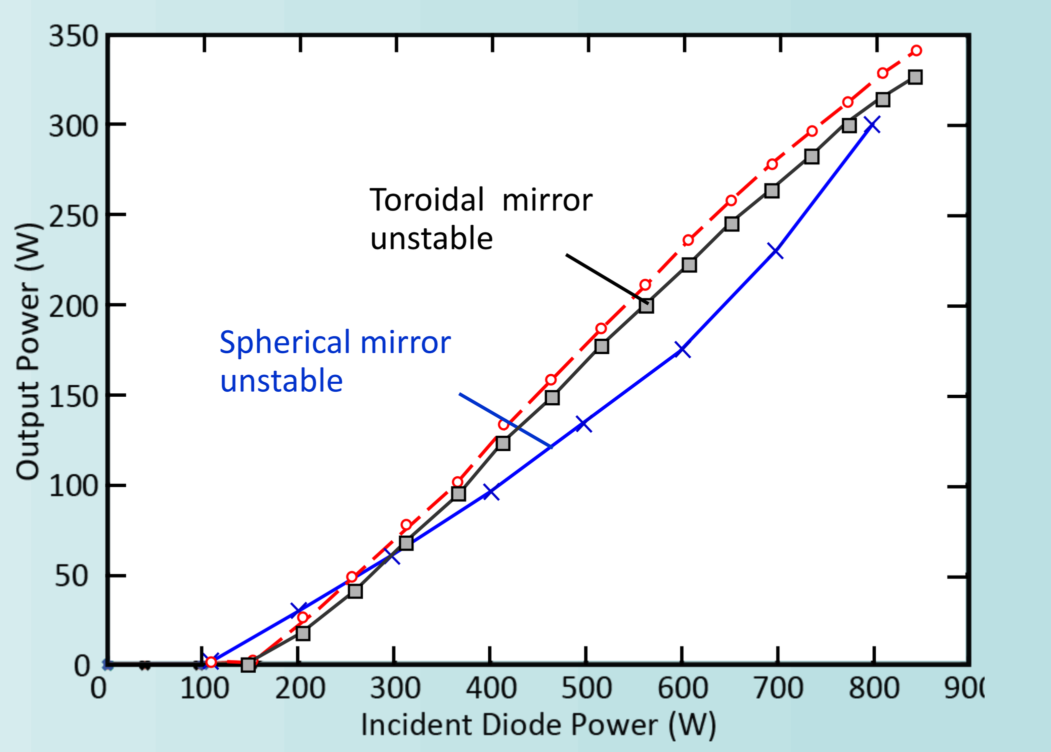


Negative branch UR resonator with toroidal rear mirror

- Selection of toroidal micro-stripe mirrors tested in a 20% output coupling UR with 230mm nominal RoC cylindrical substrate
- 23.4 mm RoC gave best output properties at 10 mm spacing from waveguide facet
- Easily aligned, as there is sharp improvement in beam quality and output power as the stripe is scanned vertically through the correct height and rotated about laser axis

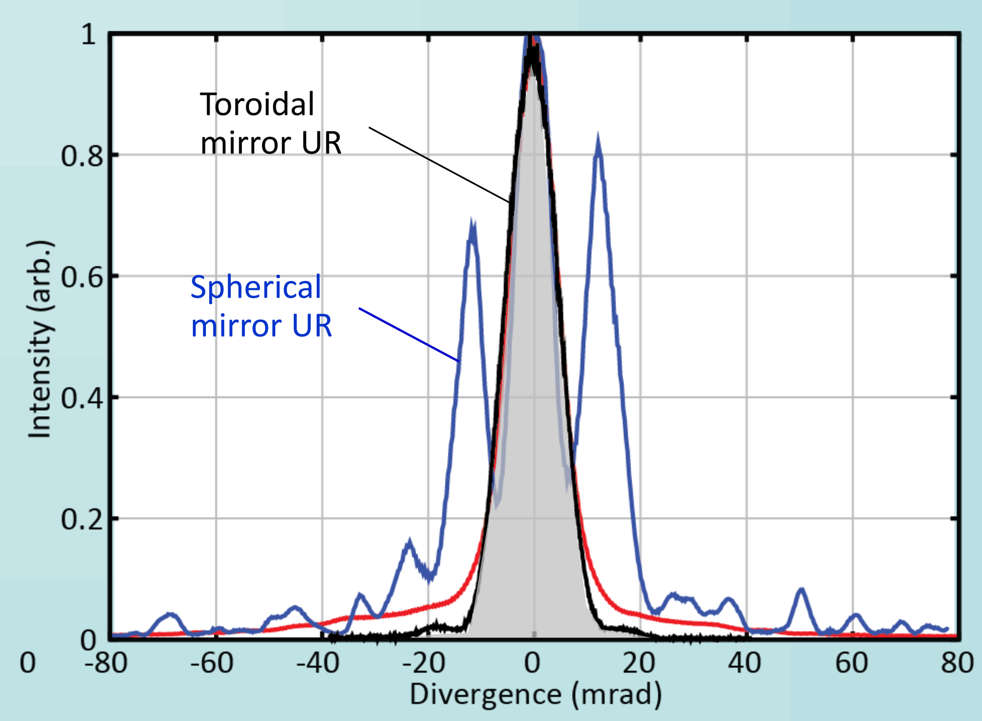


Power output



- •Power output now matches multimode
- •326W with current diode pumps
- •M^2 good- clean beam with minimal cladding light

Far field profile improvement in vertical axis



Outcomes

- Resonator quality micro-stripe toroidal mirrors made by laser machining
- Excellent mode quality for further development of lasers using planar waveguide gain sections
- Mirrors applicable to folded configurations in planar waveguide MOPA

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