Polymer Optical Waveguide Fabrication Using Laser Ablation

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Loughborough University

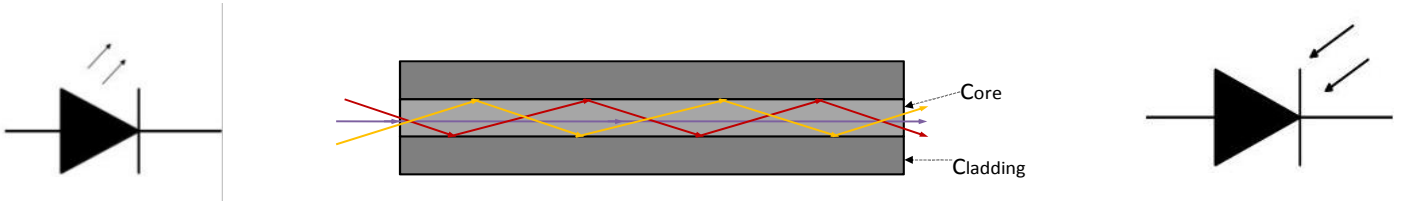
Presentation Overview

- Introduction
- Optical communication overview
- *IeMRC* OPCB flagship project
- Laser ablation of optical waveguides
- Results
  - System characterisation
  - Waveguides
- Challenges
- Summary

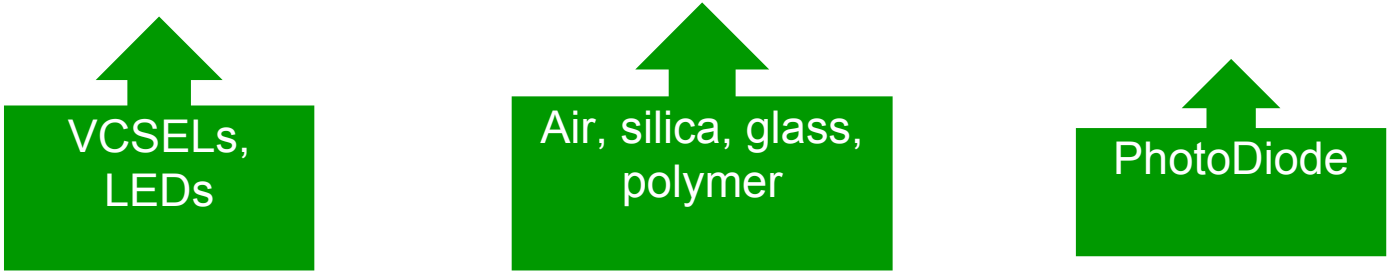
Optical Communication System

Block / Module

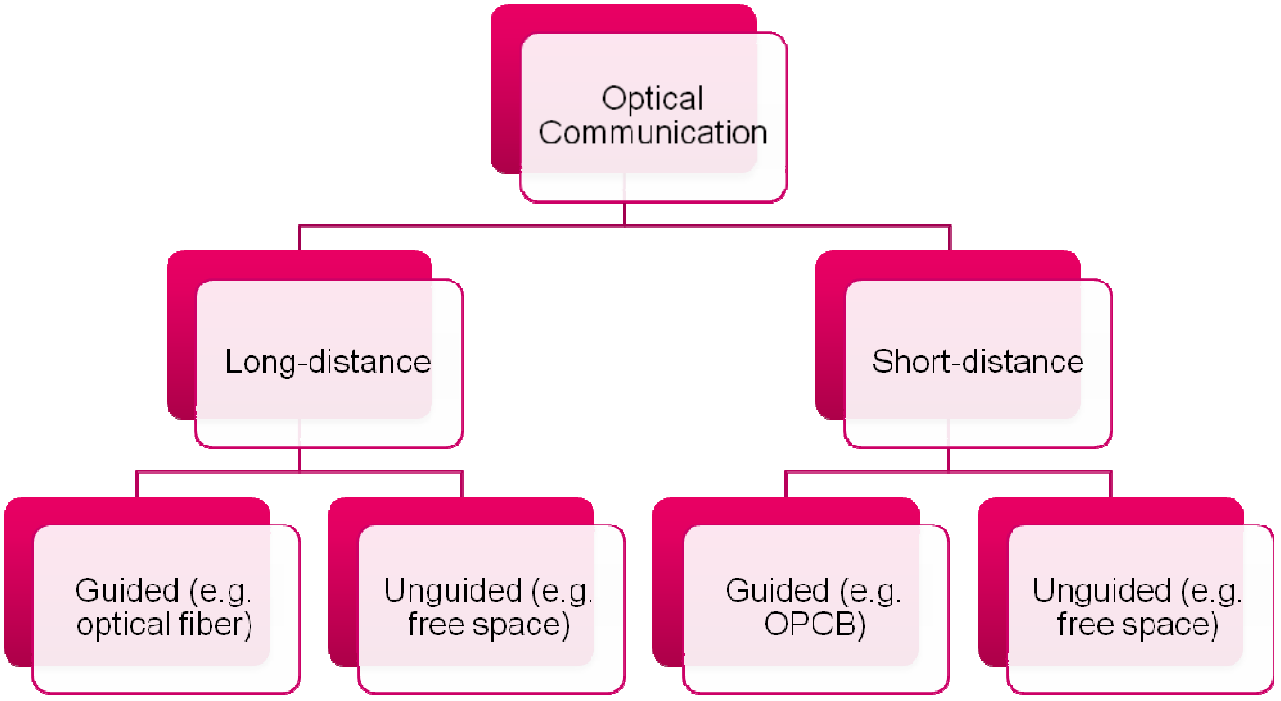
Principle



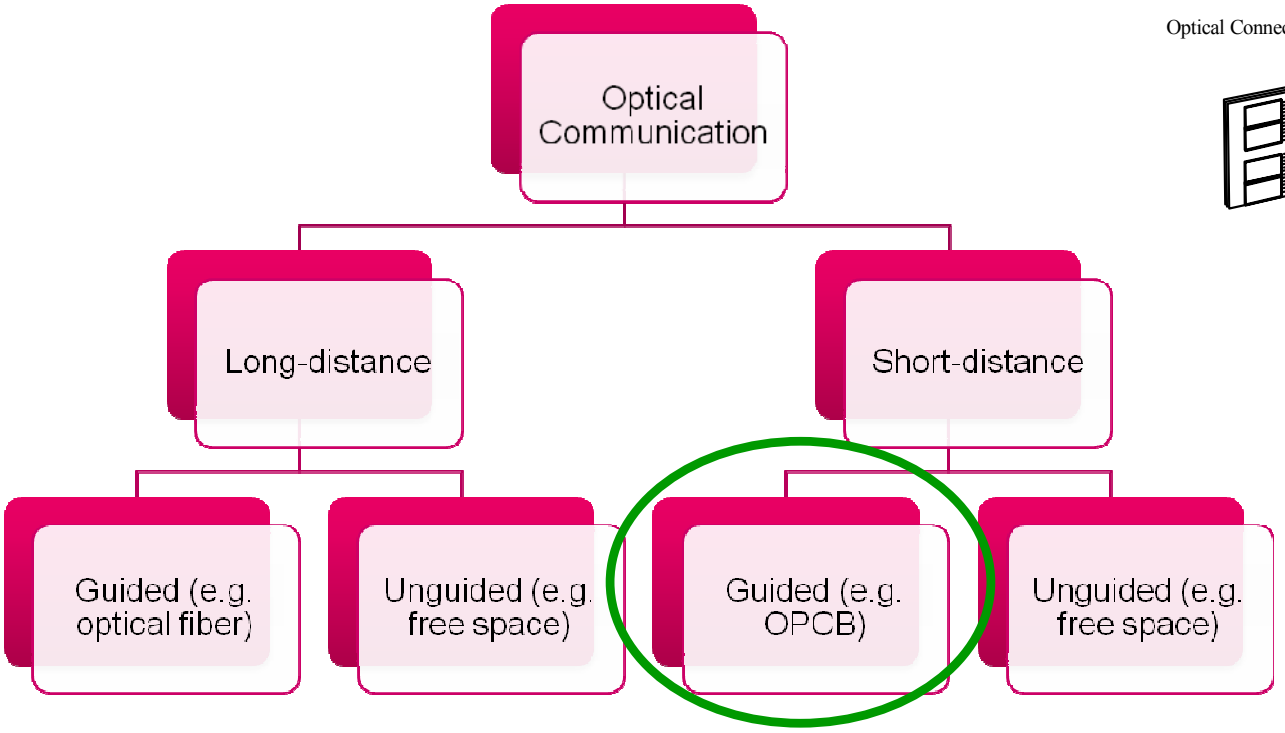
Element / Component

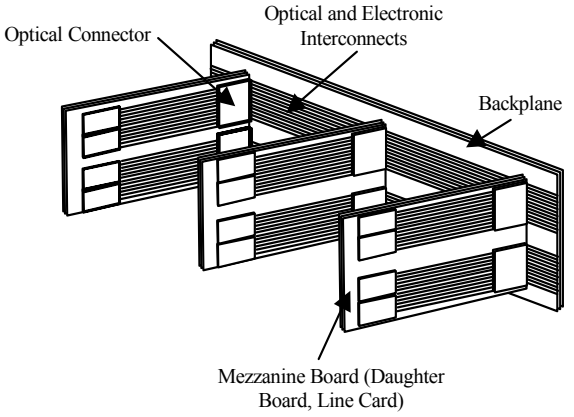


Optical Communication Methods



Optical Communication Methods



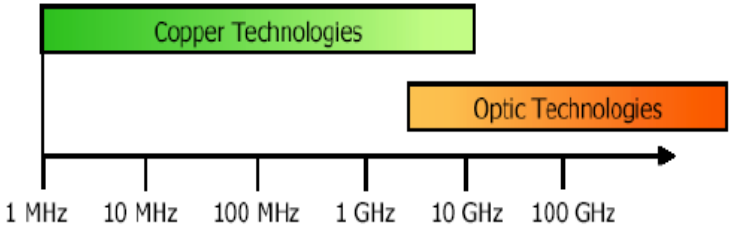


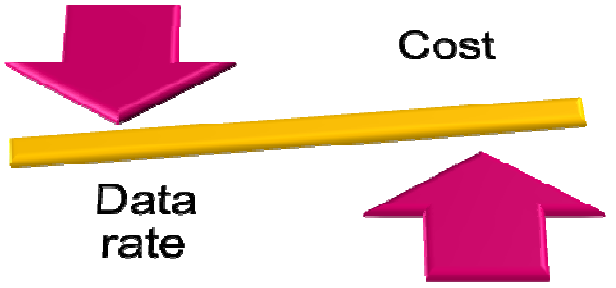
OPCB or Optical Printed Circuit Board is the integration of optical waveguides with electrical printed circuit boards (PCBs) to solve the bottlenecks on the current electrical connections on PCBs.

Why

Current Challenges in PCBs for High Data Rates

- **Copper interconnection Limitation**
  - Copper transmission reaches limits
  - HDI cannot absolutely solve the density challenges in PCB industry
  - EMI, crosstalk, reflection, etc. at high frequency
- **Optical Interconnection Benefits**
  - High data rate
  - Multiple signals of different wavelengths (WDM)
  - Relative cost effectiveness
  - No EMI issue





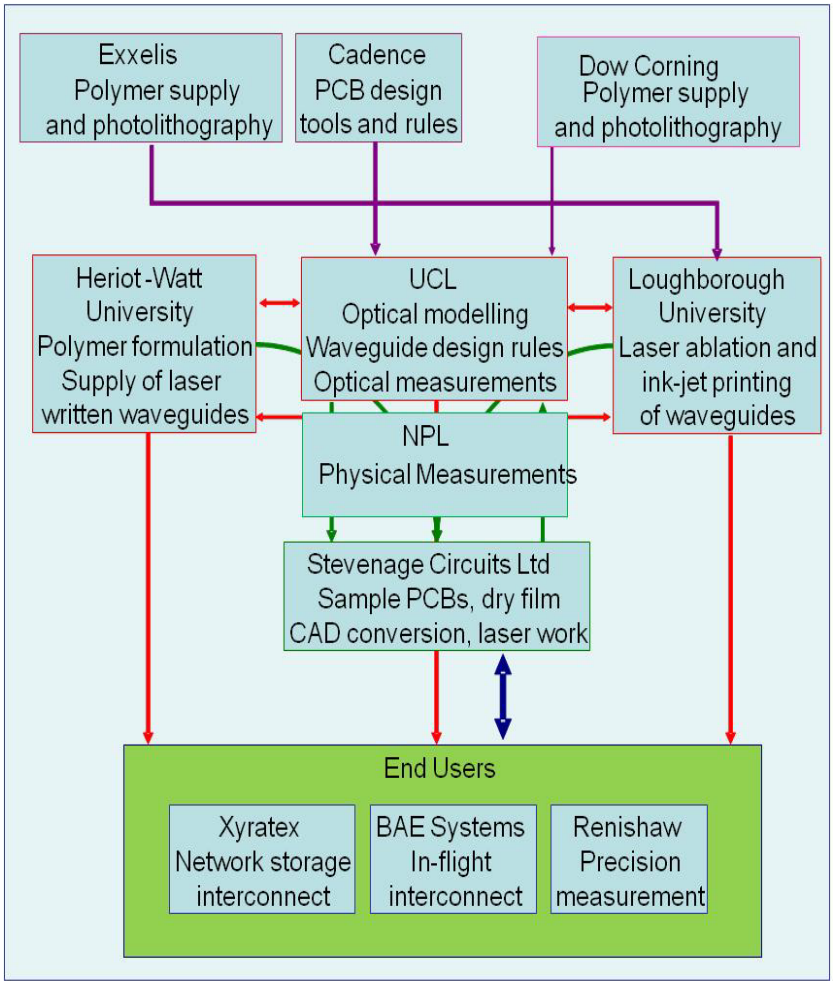
IeMRC OPCB Flagship Collaboration

Project Aims:

- Establishing waveguide design rules
- Developing low cost manufacturing techniques
- Understanding the effects of
  - waveguide wall roughness
  - cross sectional shape

on the behaviour of light and the effect on waveguide loss

- **Academic partners**: Loughborough University, Heriot-Watt University and University College London
- **Industrial partners**: Xyratex, Stevenage Circuits, Renishaw, BAE Systems, Exxelis, Dow Corning, Cadence and NPL



Optical Waveguide Fabrication Techniques

- Photolithography
- Laser direct writing
- Inkjet-printing
- Embossing
- Laser ablation
  - Photochemical (UV sources, e.g. Excimer)
  - Photothermal (IR sources, e.g. CO_2)

Research processes and procedures

FR4 Substrate

Spin coating of optical polymer

Truemode™ | Polysiloxane

UV curing

Oven curing

FR4 substrate with optical layer deposited

Laser micromaching (Ablation)

Excimer Laser | UV Nd:YAG Laser | CO_2 Laser

Sample with ablated structures

Sample preparation (i.e. cleaning)

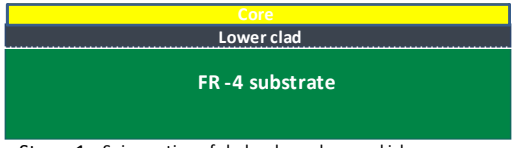
Deposition of upper cladding

Sample preparation, measurement and analysis

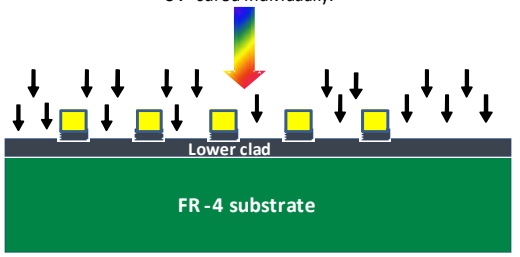
Stage 1

Stage 2

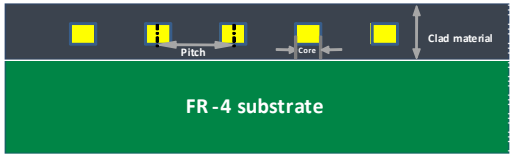
Stage 3



Stage 1 : Spin coating of clad and core layers which are UV-cured individually.

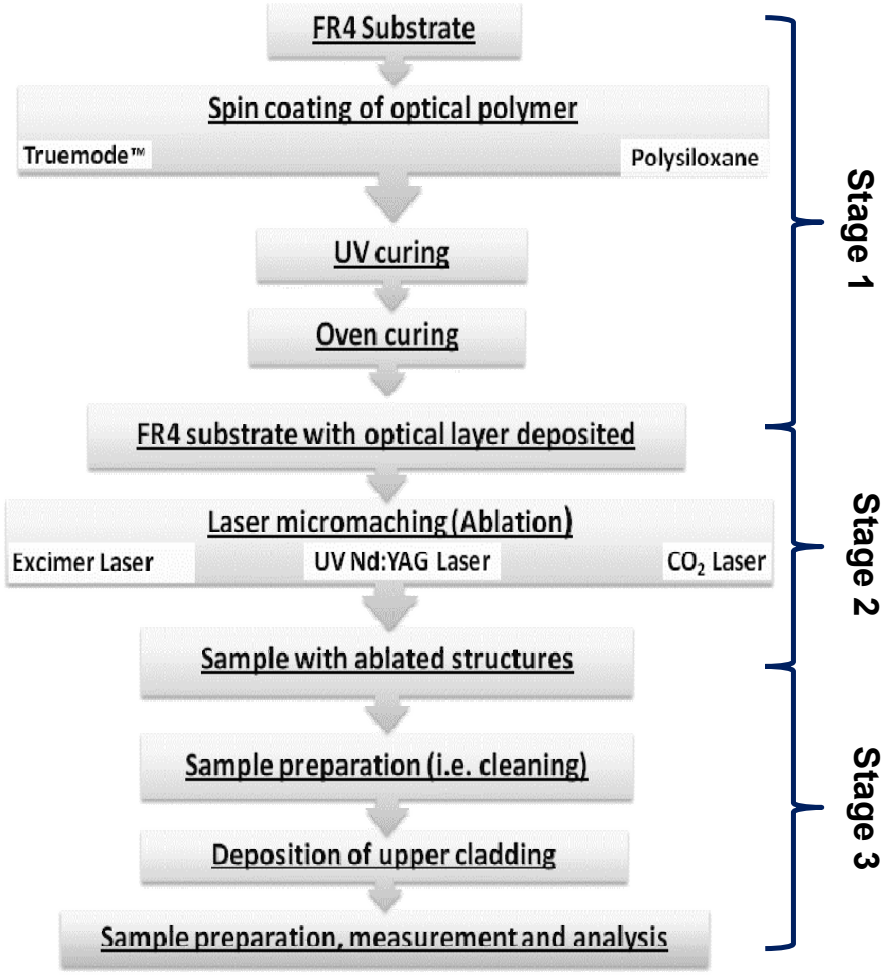


Stage 2 : Laser ablation of optical layer from the core through to clad layer



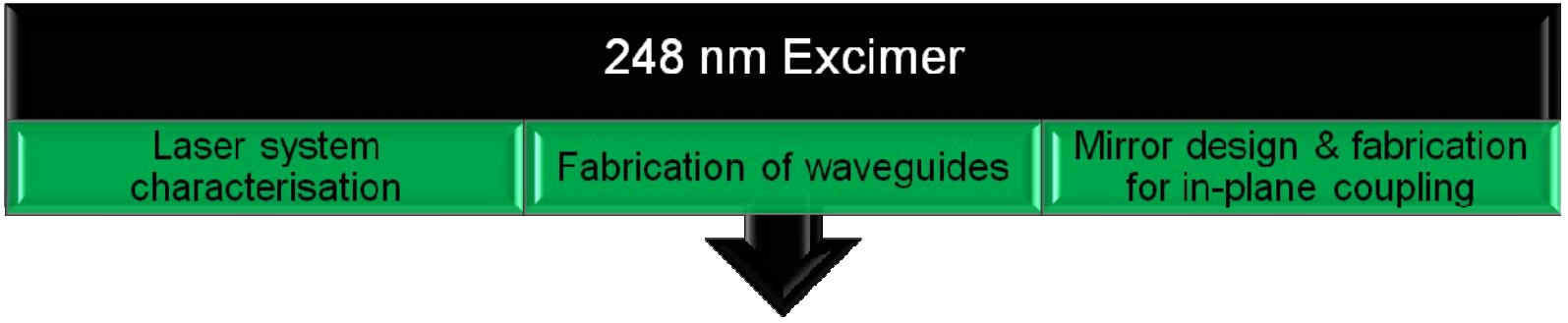
Stage 3 : Deposition of upper cladding

Research Processes and Procedures



- Materials
  - Truemode – poly acrylate, supplied by Exxelis
  - OE4140 / OE4141 polysiloxane supplied by Dow Corning
  - Both UV cure photopolymers
- Lasers
  - CO_2
  - UV Nd:YAG
  - Excimer

Laser System & Experimental Investigation



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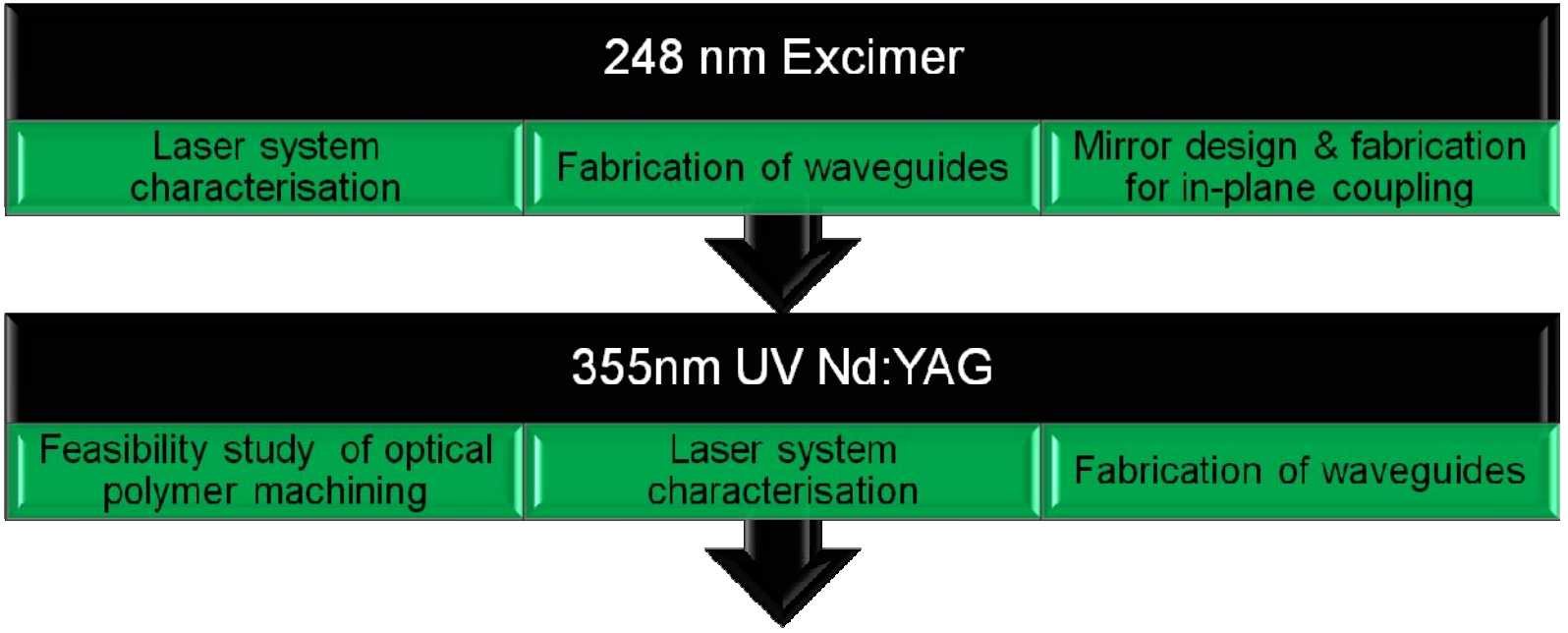
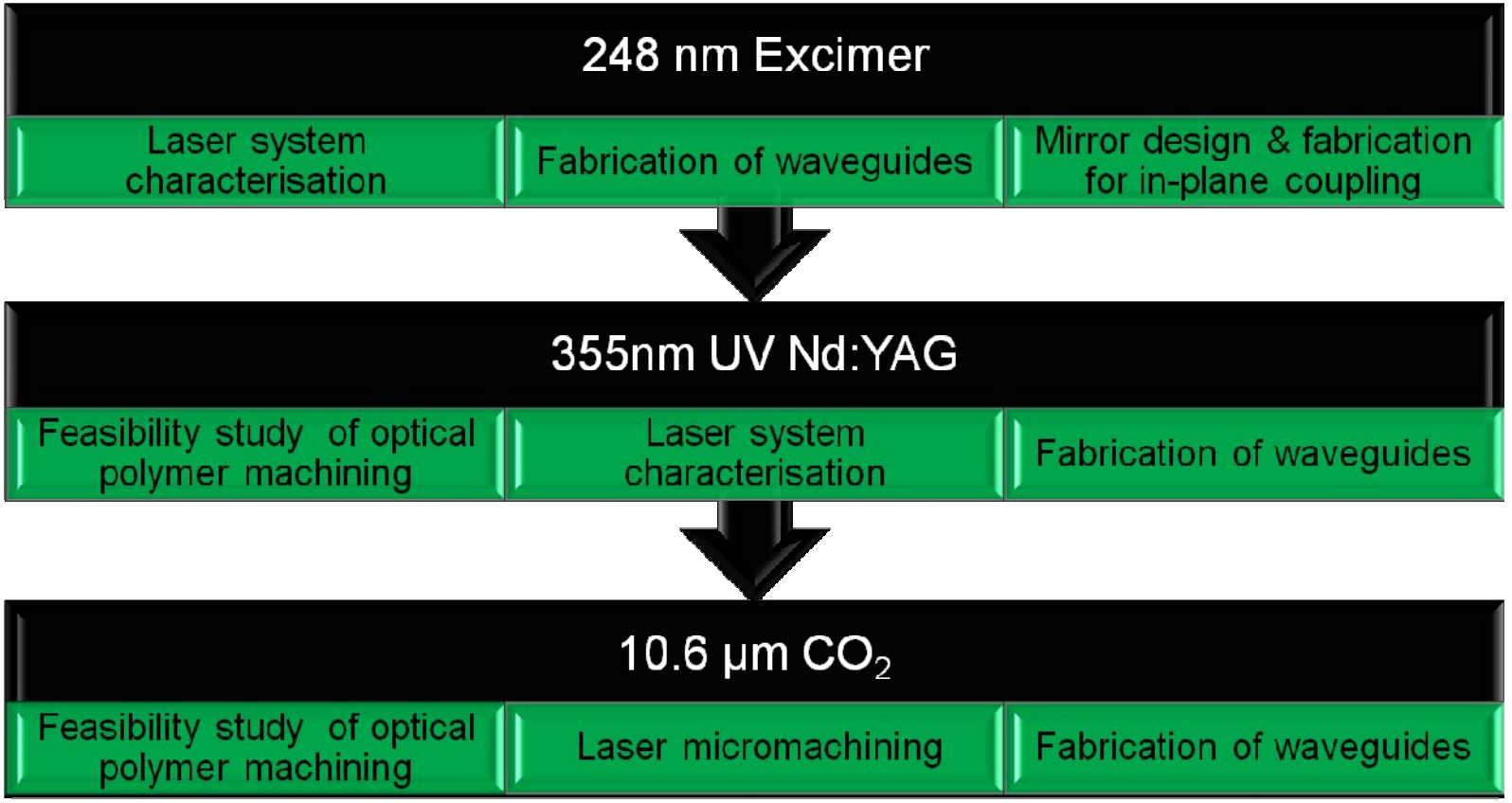
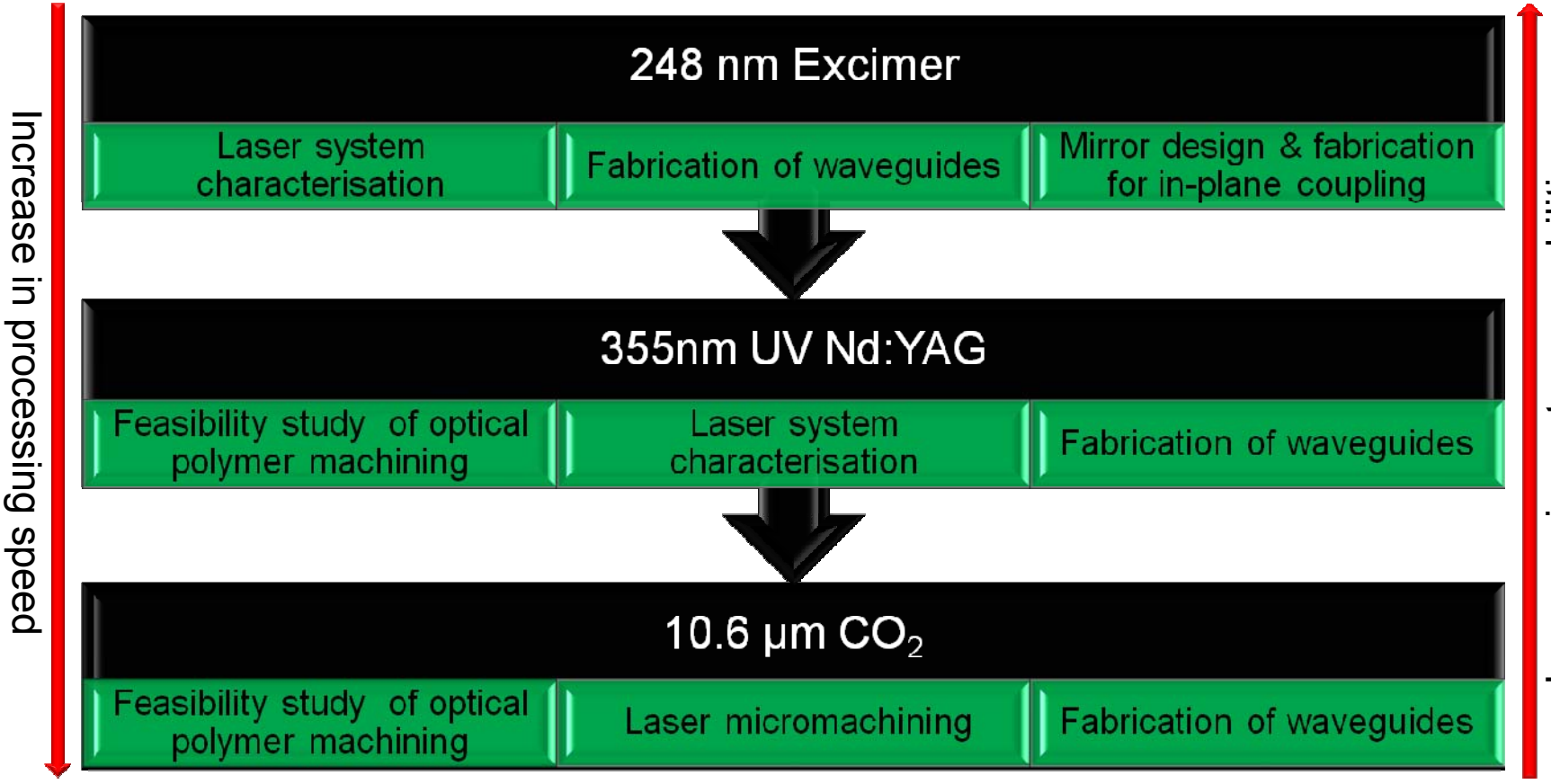


Laser System & Experimental Investigation

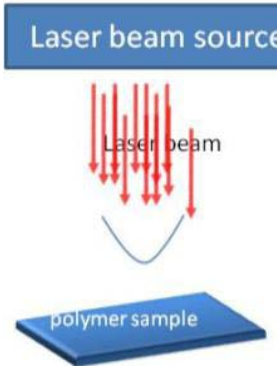


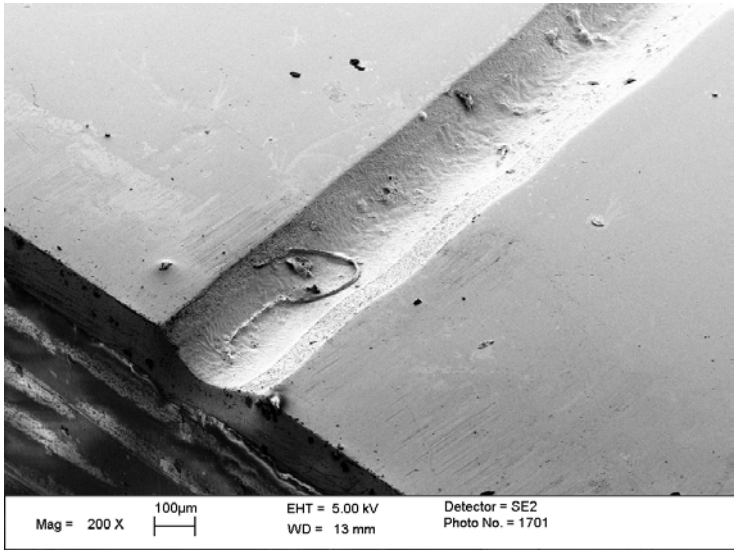
Laser System & Experimental Investigation



CO_2 Laser Ablation of Optical Waveguides

- CO_2 Laser System
  - 10 Watt (max.) power
  - Wavelength = 10.6 μm
  - Continuous Wave (CW)
  - Gaussian beam profile
- Investigation
  - Photothermally-dominated ablation process
  - Feasibility study conducted
  - Effect of translation speed & power was investigated
- Material
  - Polysiloxane
  - Truemode - polyacrylate

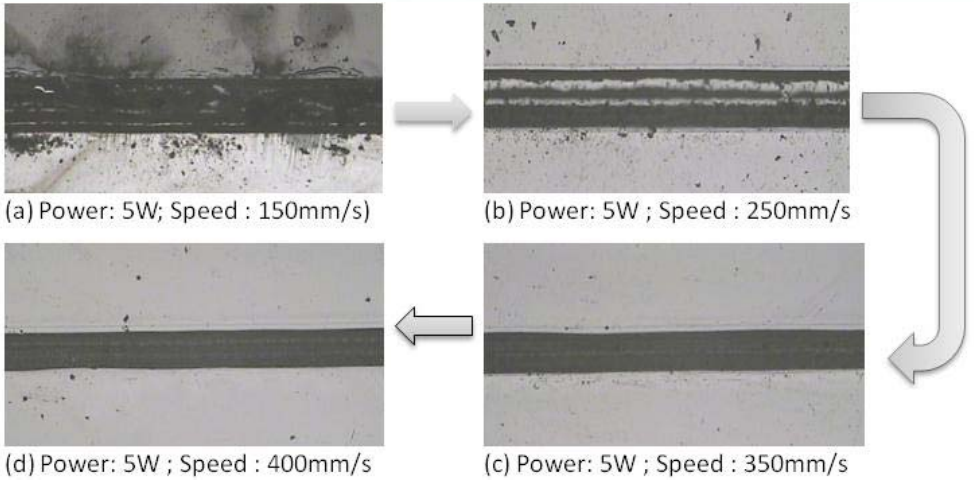




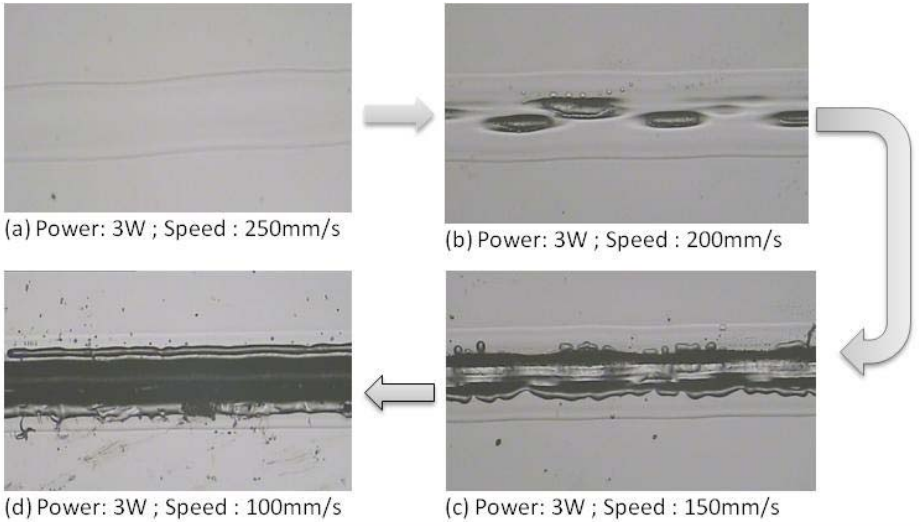
Line ablated using the Gaussian beam profile CO_2 laser

CO_2 Laser Machining Trials

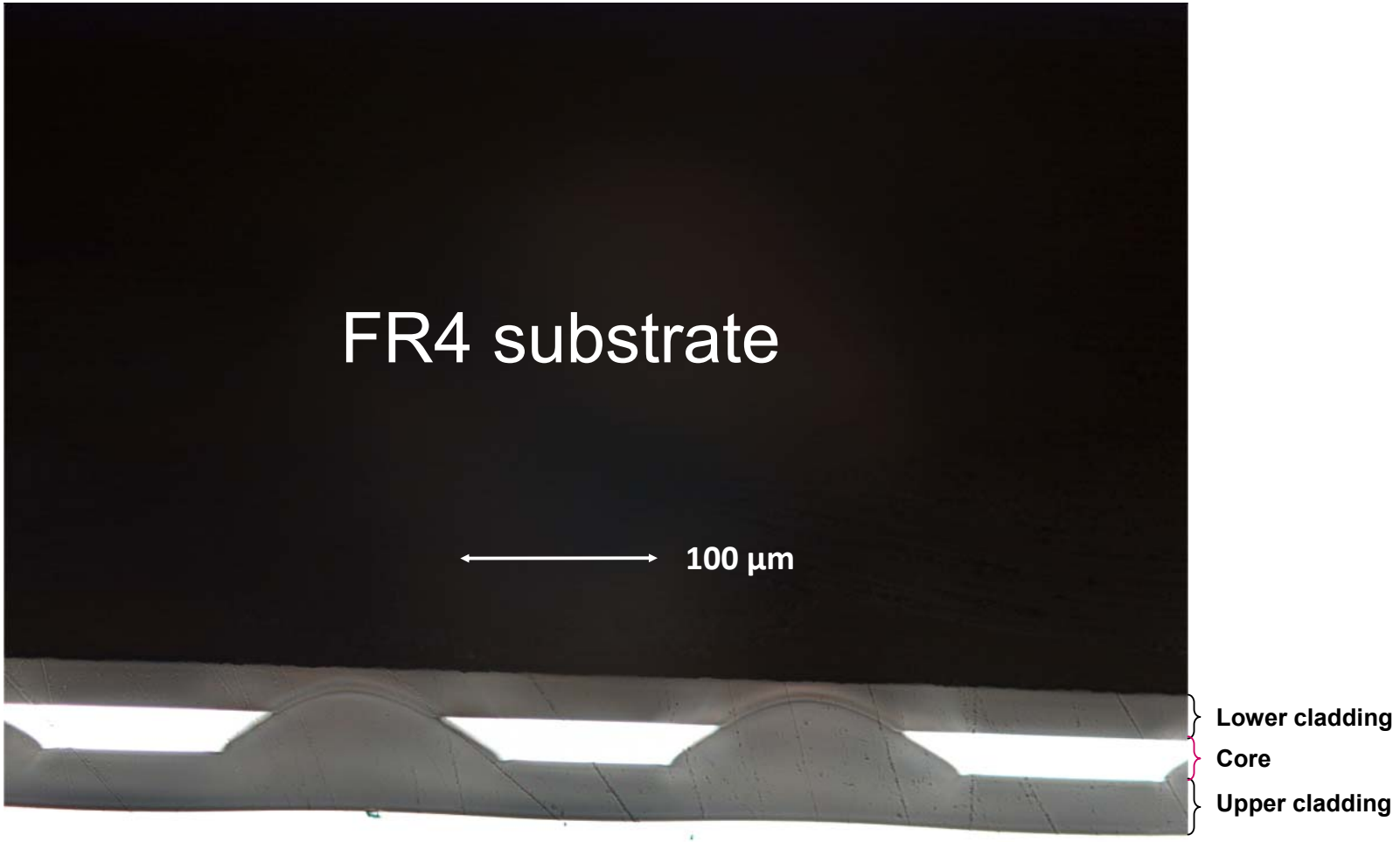
Effect of scanning speed at a fixed 5 W power on the quality of ablation of Polysiloxane using CW CO_2 laser



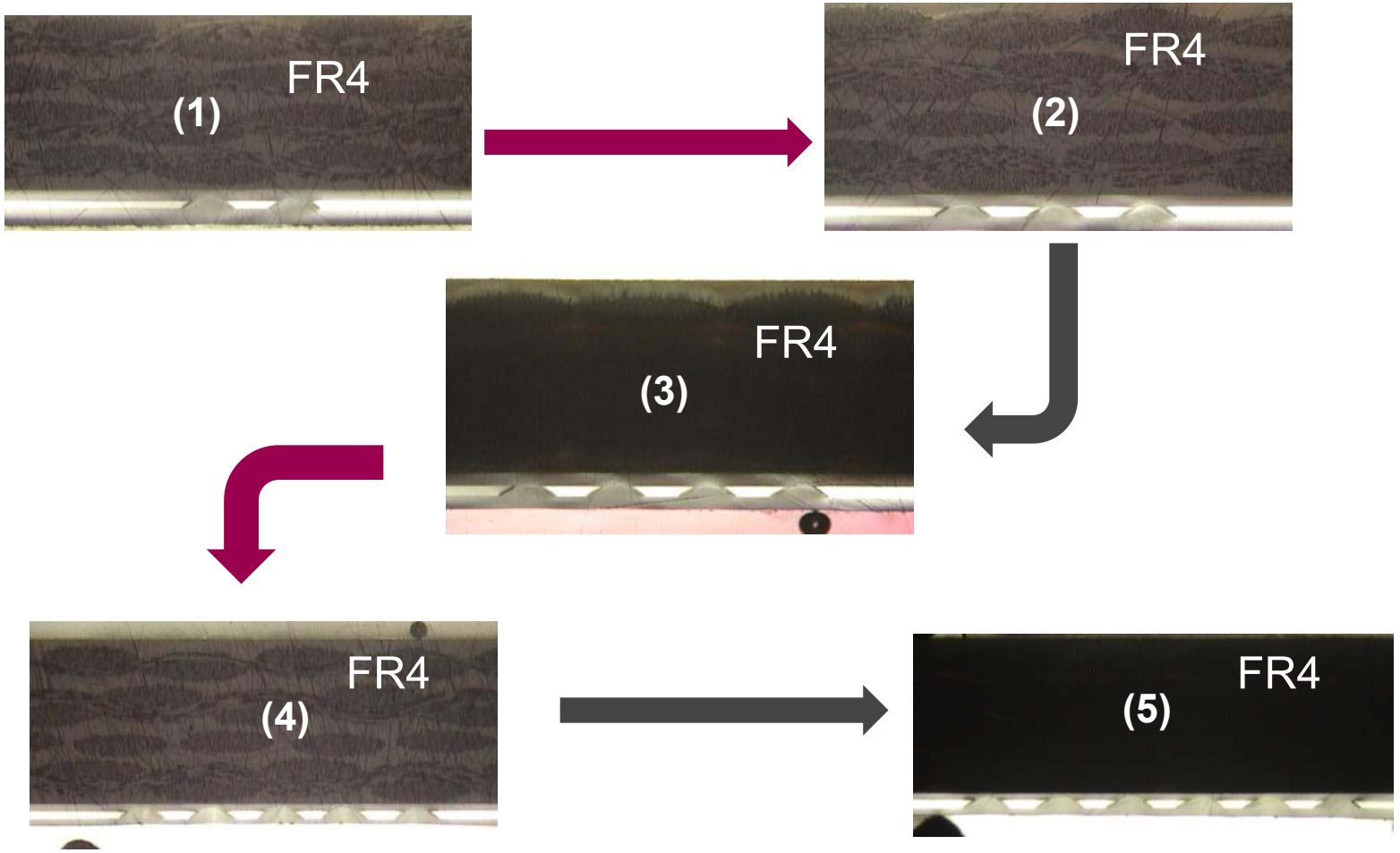
Effect of scanning speed at a fixed power of 3 W on the quality of ablation of Truemode™ polymer using CW CO_2 laser



CO_2 Laser Ablation of Optical Waveguides



CO_2 Laser Ablation of Optical Waveguides



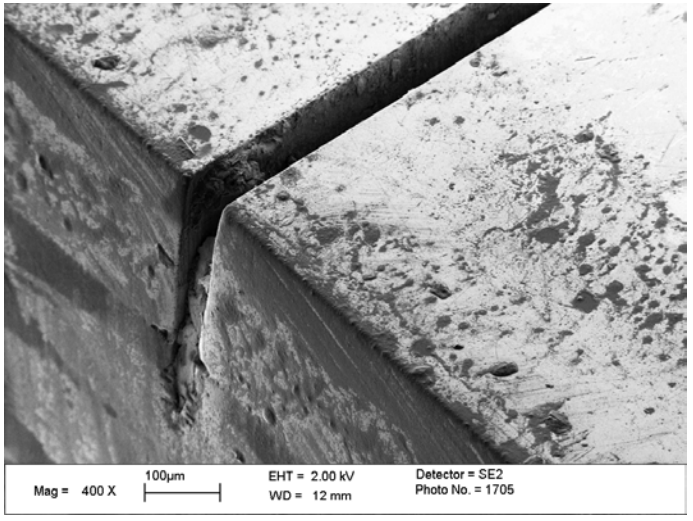
UV Nd:YAG Laser Ablation with Stevenage Circuits Ltd

UV Nd:YAG Laser Systems

Parameter / Model	ESI model 5200	ESI Flex 5330
Wavelength (nm)	355	355
Beam profile	Gaussian	Gaussian & top-hat
Frequency (kHz)	20 (max.)	70 (max.)
Spot size (μm)	25 (fixed)	53 – 123 (changeable)
Power (W)	Up to 2.5 (approx.)	Up to 3.3 (approx.)
Pulse width (ns)	30	60

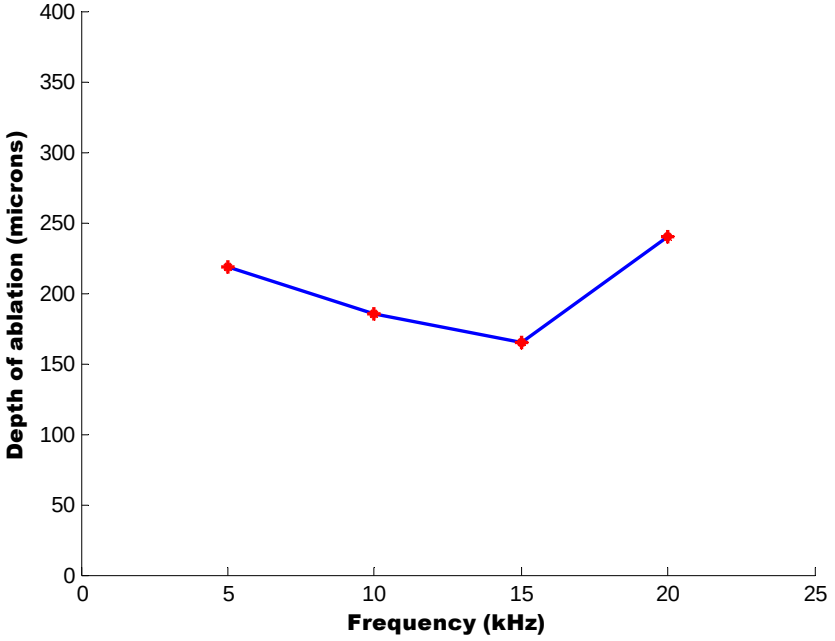
Investigation

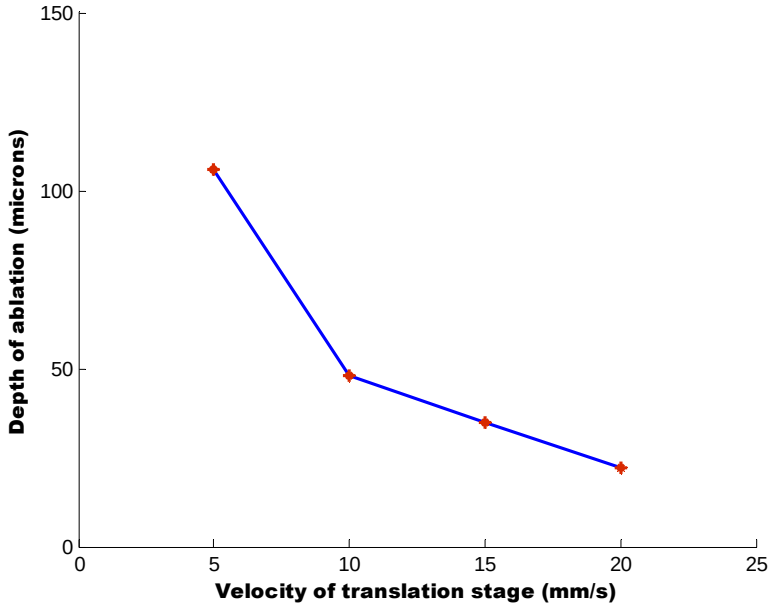
- Laser system characterisation
- Waveguide fabrication
- Effects of stage speed, laser power & pulse frequency were investigated



Gaussian beam profile of UV Nd:YAG laser (5200 model)

UV Nd:YAG Machining Characterisation

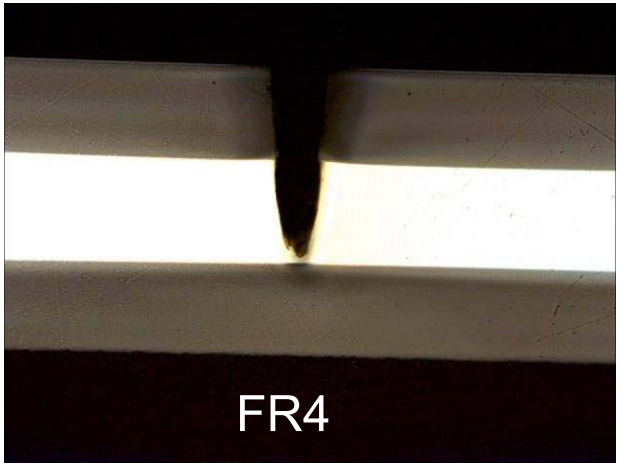


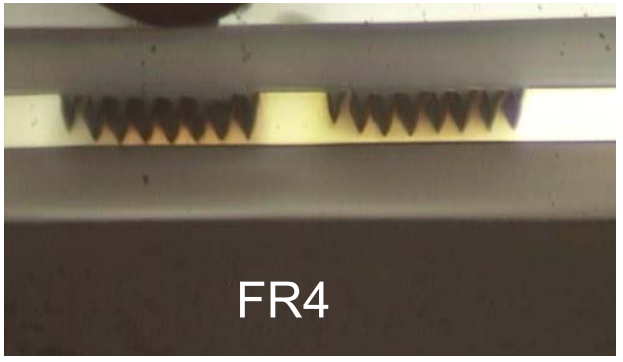


UV Nd:YAG laser system characterization using Truemode optical polymer showing: (a) Graphical representation of the effect of frequency on depth of ablation at constant power of 0.1 W, translational stage speed of 5 mm/s and 4 laser passes, (b) Graphical representation of the effect of stage speed on the depth of ablation at 0.1 W and 5 kHz with 2 laser passes.

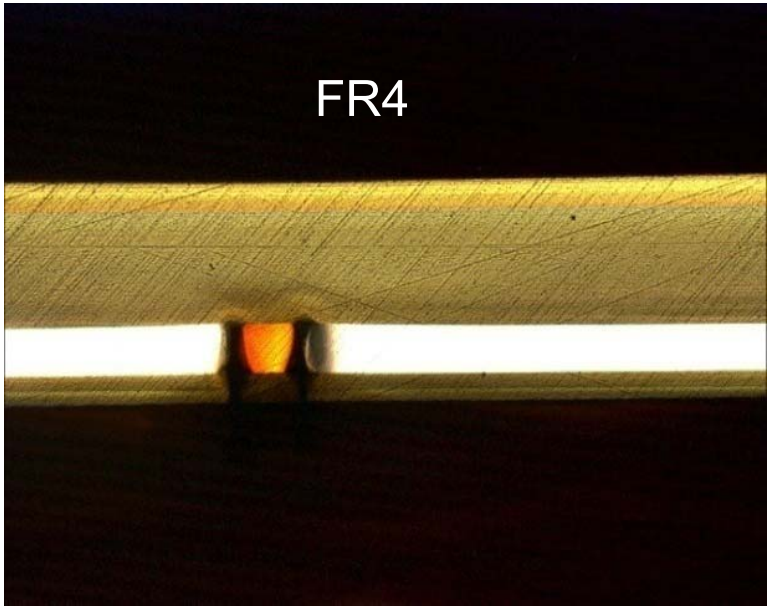
UV Nd:YAG Laser Ablation Beam Overlap

- Issues were encountered overlapping the narrow beam to form trenches
- Methods to overcome this developed

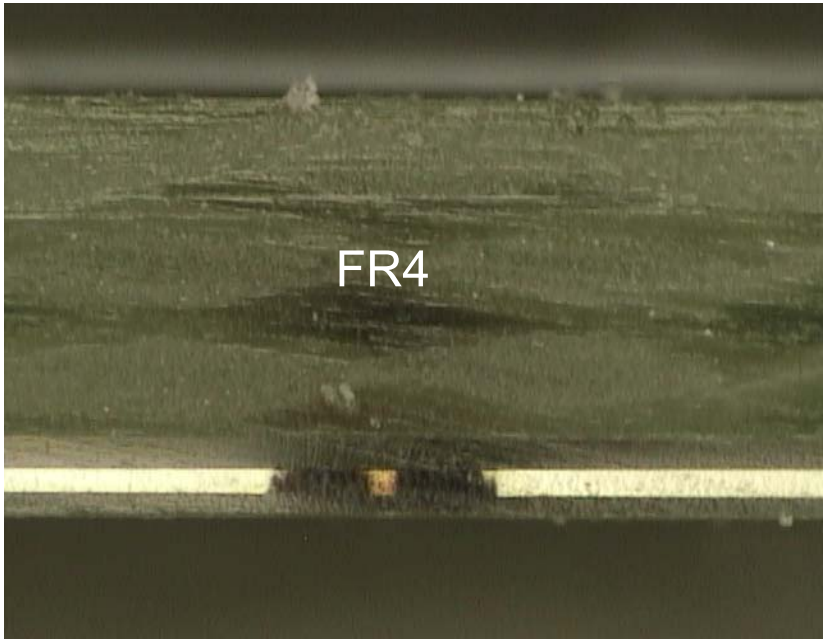




UV Nd:YAG Laser Ablation of Optical Waveguides



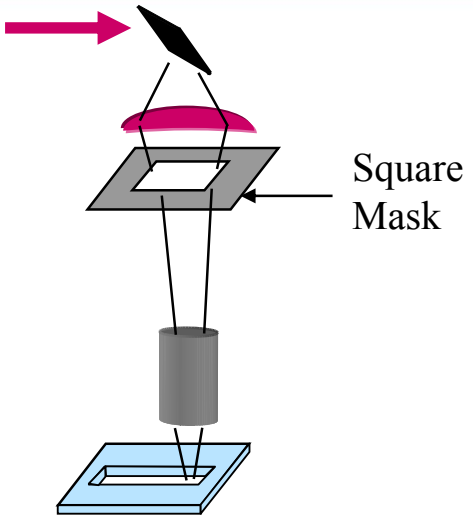
Waveguide of 35 µm x 70 µm made in Truemode material using Flex 5300 model of UV Nd:YAG



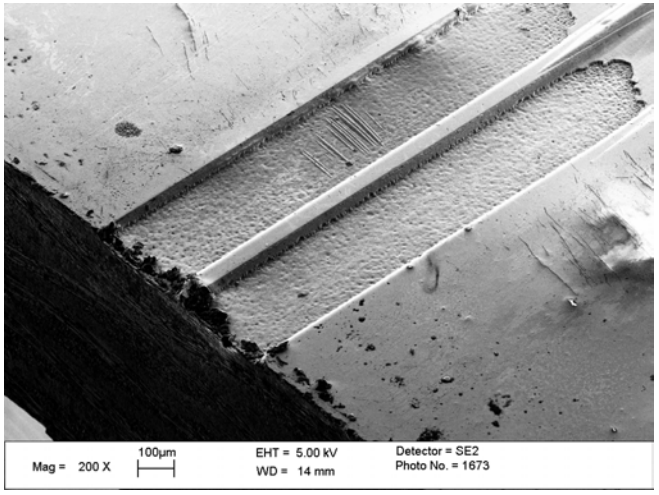
Waveguide of 45 µm x 45 µm made in Truemode material using 5200 model of UV Nd:YAG

Excimer Laser Ablation of Optical Waveguides

- ## Excimer Laser System
  - 248nm Wavelength, Krypton Fluoride (KrF),
  - 20 nm Pulse Length, 1- 40Hz
  - 250mJ/pulse (max.) in energy mode or 27kV (max.) in Voltage mode
  - Up to 100 mJ/pulse over 1 mm^2 at the workpiece
- ## Investigation
  - Laser system characterisation
  - Waveguide fabrication
  - Effects of stage translation speed, fluence & frequency were investigated
- ## Material
  - Truemode
  - Polysiloxane



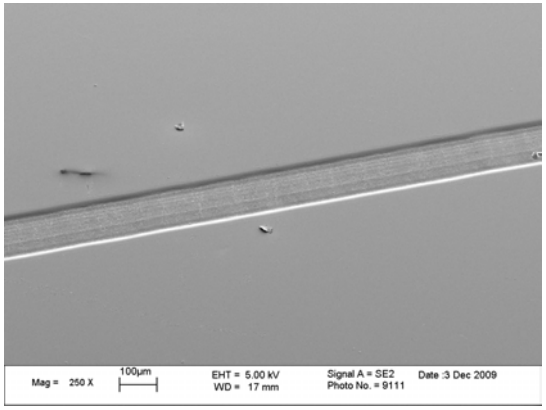
'Top-hat' like beam profile (as a result of mask projection) of Excimer laser trial

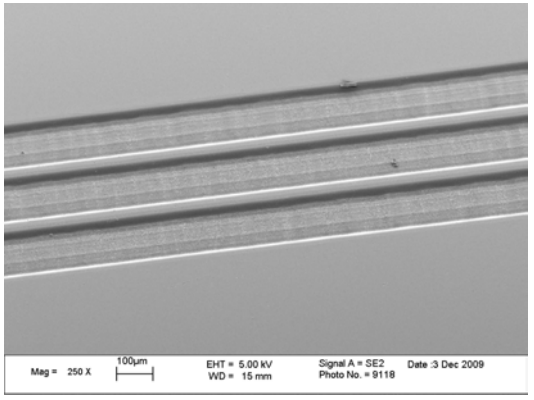


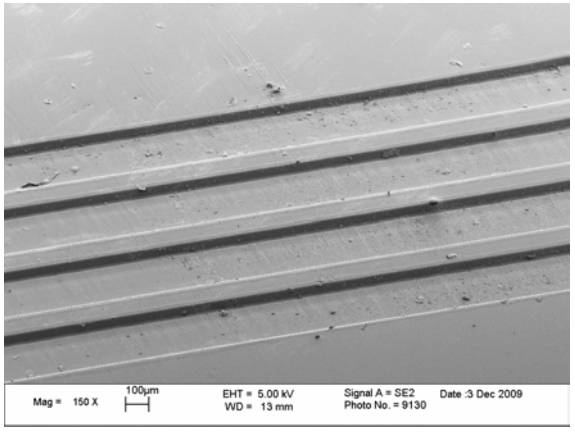
Excimer Laser Fabricated Waveguide Structures

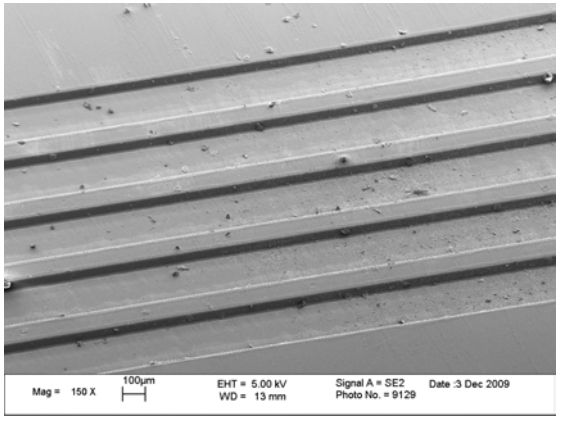
Investigations

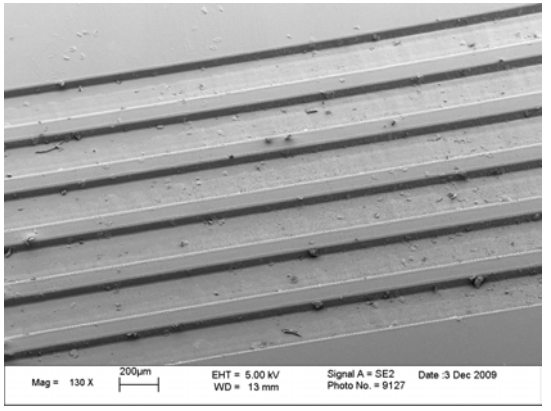
- Different
- Speed
- Fluence
- Optical density
- Waveguide width



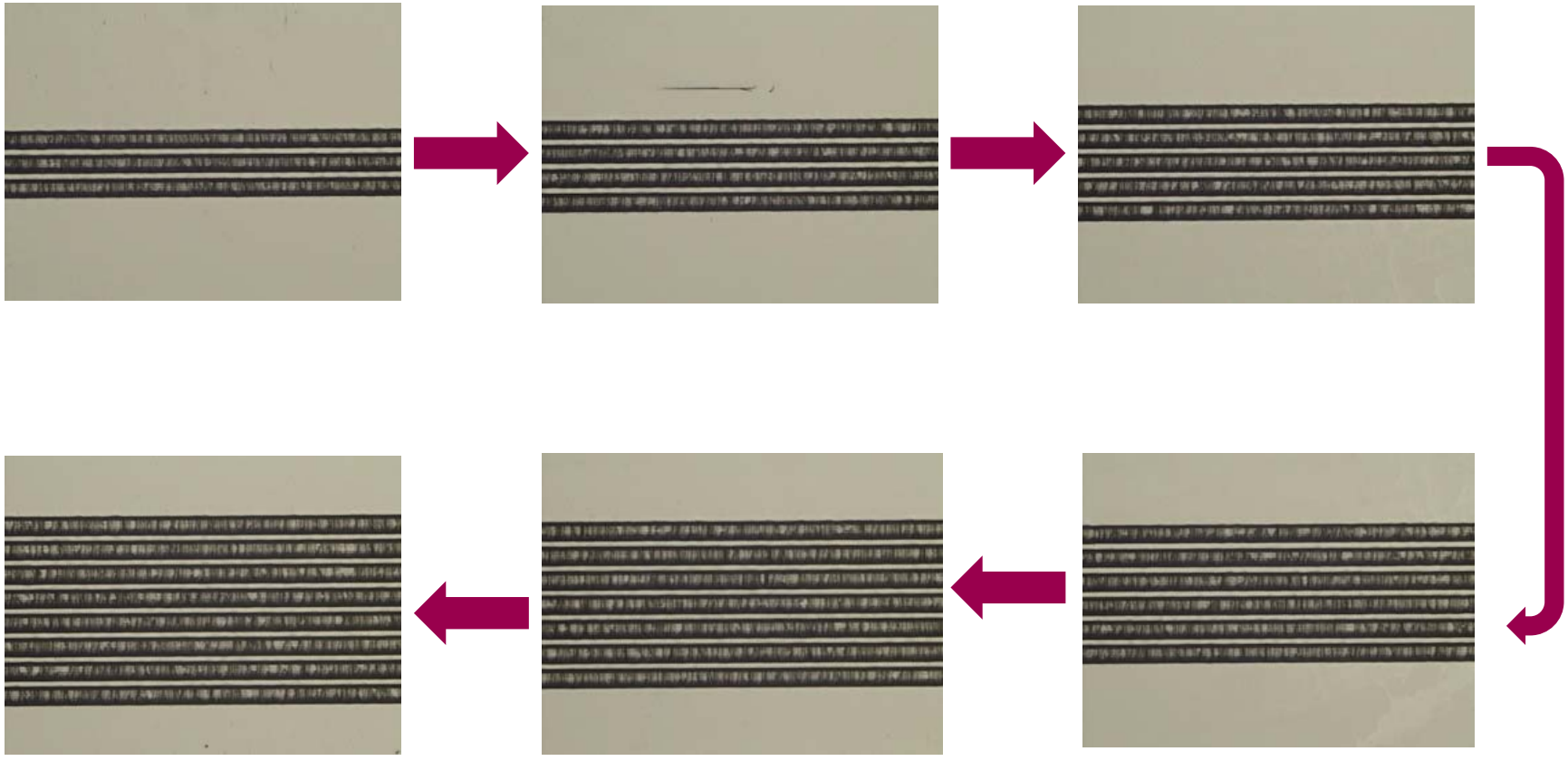








Excimer Laser Fabricated Waveguide Structures



Excimer Laser Fabricated Waveguide Structures

Excimer laser ablation of 50 μm x 35 μm multimode waveguide in Truemode optical polymer

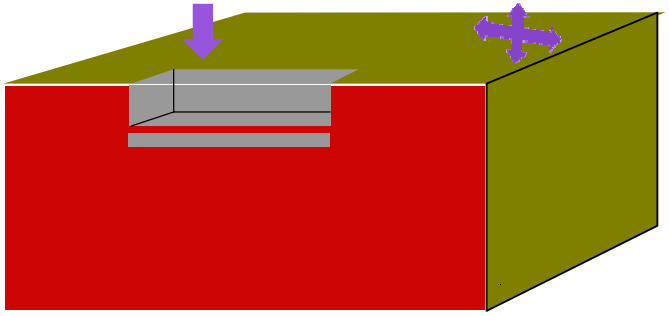
Comparison of Laser Processing Methods

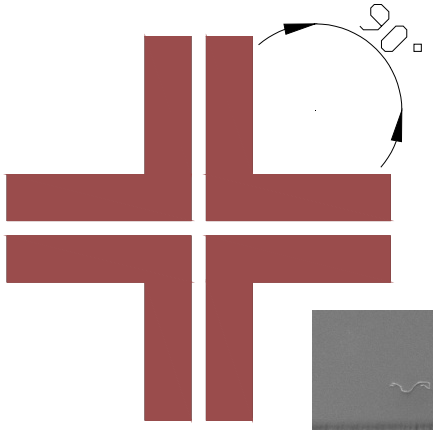
Features / Laser	CO_2 Laser	UV Nd:YAG Laser	Excimer Laser
Wavelength	10.6 μm (IR)	355 nm (UV). Other wavelengths available	248 nm (UV). Other wavelengths available
Beam –polymer interaction	Photothermal	Photothermal-photochemical	Photochemical
Processing speed	Very high (e.g. 1000 mm/s)	Moderately high (500 mm/s)	Low (e.g. 1,500 mm/min)
Mask projection	No	No	Yes
PCB process	Widely used	Widely used	
	CW common but pulsed also available	CW common in IR wavelengths but pulsed Q-switched are common in UV harmonics	Mostly in pulsed mode

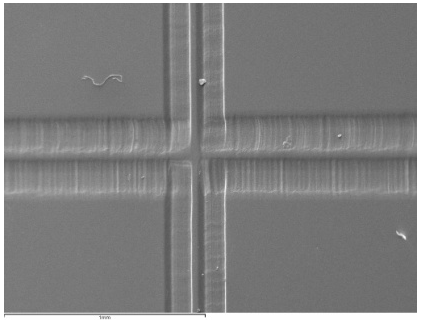
- Increase in system capabilities, increase in ablation quality due to the dominance of photochemical behaviour
- Decrease in processing speed and relative increase in manufacturing cost

Further Challenges

- Loss measurements
  - Measurements are underway at UCL
  - Initial measurements indicate relatively high losses
- Wall Roughness measurement
  - Initial measurements underway, but accessing the edge of features is problematic
- Preparation of crossings and mirrors







Cross-over waveguides trial

Summary

- Waveguide fabrication has been demonstrated using 10.6 μm CO_2 & 248 nm Excimer lasers at Loughborough University
- Waveguide fabrication has been demonstrated using 355 nm UV Nd:YAG at Stevenage Circuits Limited
- Propagation loss measurement on the waveguide samples is underway at UCL
- Many challenges for the characterisation of wall roughness and correlation with loss measurements
- Work underway to fabricate mirror structures

Thank you for your attention

Any Questions?

Acknowledgements:

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❖ Project partners:

▪University College London (UK), Loughborough University (UK) & Heriot Watt University (UK)

▪BAE Systems (UK), Cadence (UK), Dow Corning (USA), Exxelis Ltd (UK), Stevenage Circuits Ltd (UK), National Physical Laboratory (UK) and Xyratex Technology Ltd (UK),