Digital Manufacturing of Industrial Lasers

- Nathan L Macleod

Optical Stress Measurement Instrumentation

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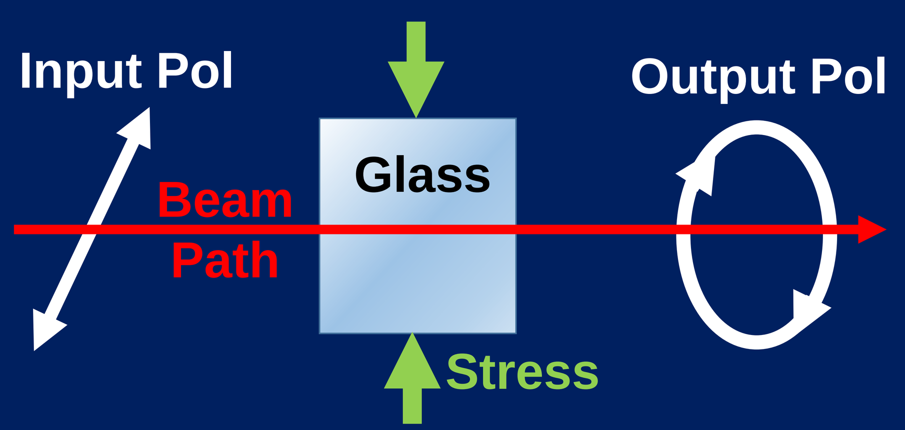
Abstract and Context

Unpredictable adhesive flow is a barrier for autonomous manufacturing of lasers. Other methods of bonding can aid robotic alignment, but these are not established. Analysing stress in optics bonded by laser welding and hydroxide catalysis bonding allows improvements to speed up industrial use. New methods in optical stress analysis were invented for this purpose making advanced devices with a significant impact on characterisation of stresses. This contributes to Scotland's position as a leader in the of manufacturing of lasers.

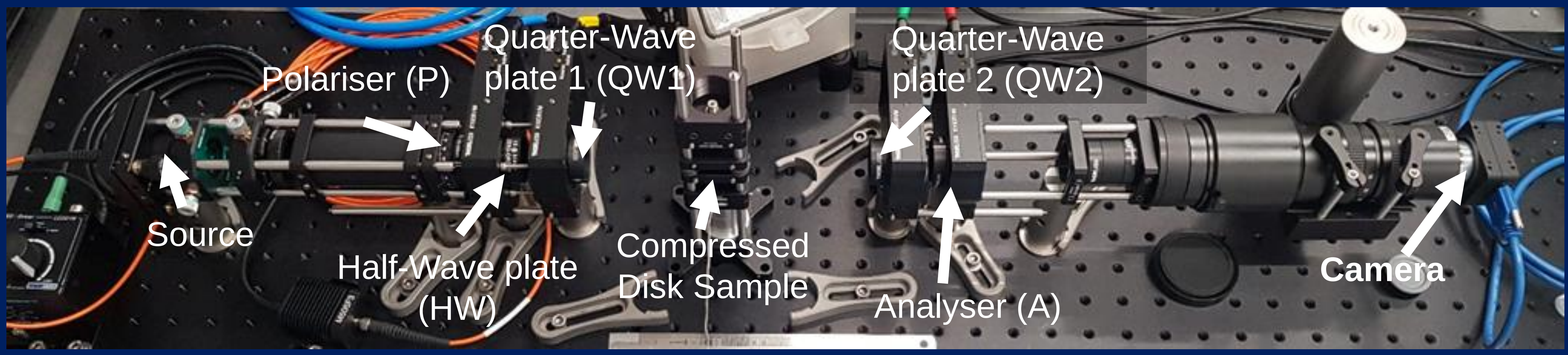
Stress and Birefringence

- Light is a transverse wave with a polarisation axis
- Horizontal and vertical polarisations can travel at different speeds in one material, a phenomena known as birefringence
- Stress produces this effect, so measures of birefringence measure stress by proxy



- The output polarisation changes depending on the isoclinic angle θ (direction of stress, in deg)
- And the retardation δ (magnitude of stress), which is how far one beam has slowed in nm

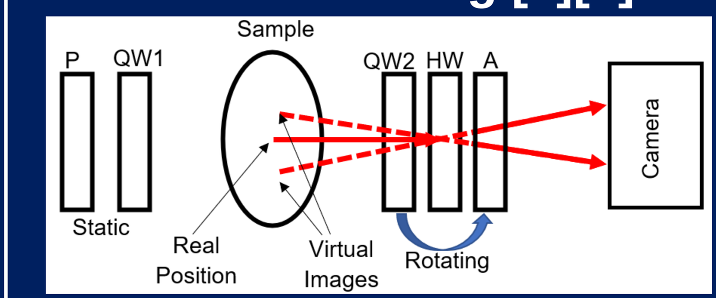
New Polariscope Instrumentation



Reversible light:
Two identical beams but opposite in direction often take the exact same path. Light is reversible.

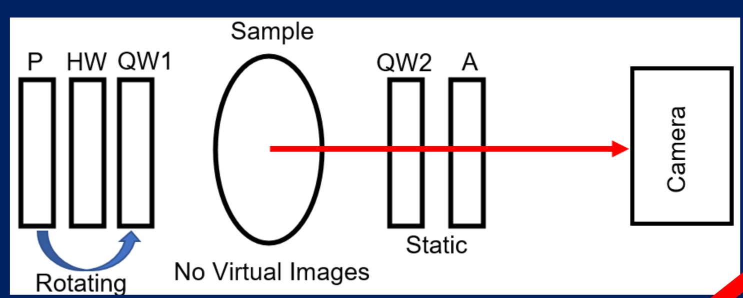
Polarisation operations are also reversible, and by reversing our part order, error in the system was reduced.

Patterson Wang [1][2]



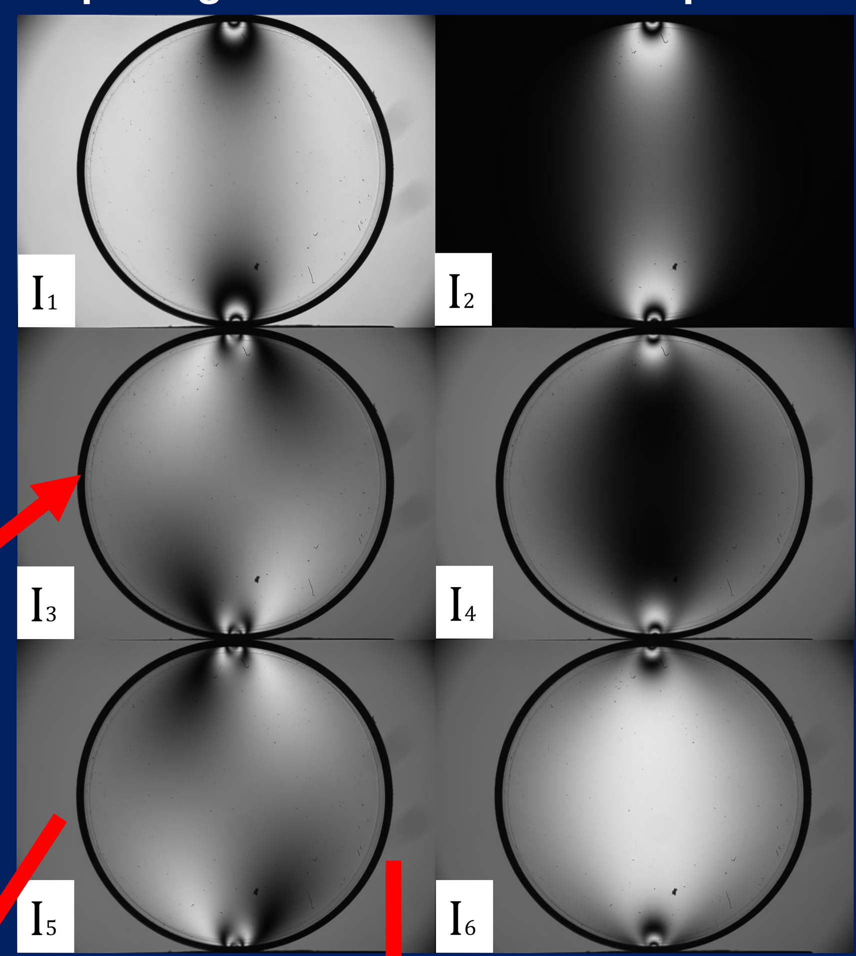
Step	P	QW1	QW2	HW	A
I_1	90°	135°	0°	22.5°	0°
I_2	90°	135°	0°	67.5°	0°
I_3	90°	135°	0°	0°	0°
I_4	90°	135°	45°	22.5°	0°
I_5	90°	135°	90°	45°	0°
I_6	90°	135°	135°	67.5°	0°

New Method: Reversed

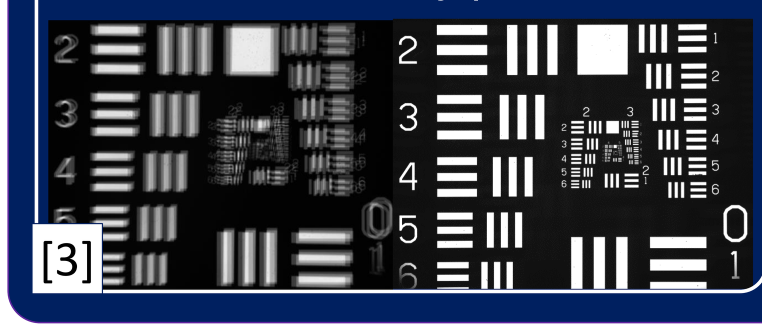


Step	P	HW	QW1	QW2	A
I_1	0°	22.5°	0°	135°	90°
I_2	0°	67.5°	0°	135°	90°
I_3	0°	0°	0°	135°	90°
I_4	0°	22.5°	45°	135°	90°
I_5	0°	45°	90°	135°	90°
I_6	0°	67.5°	135°	135°	90°

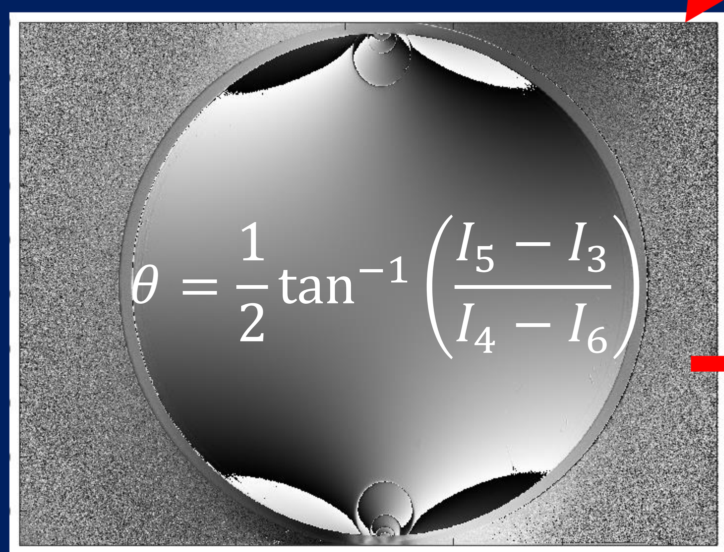
Step Images of Disk Under Compression



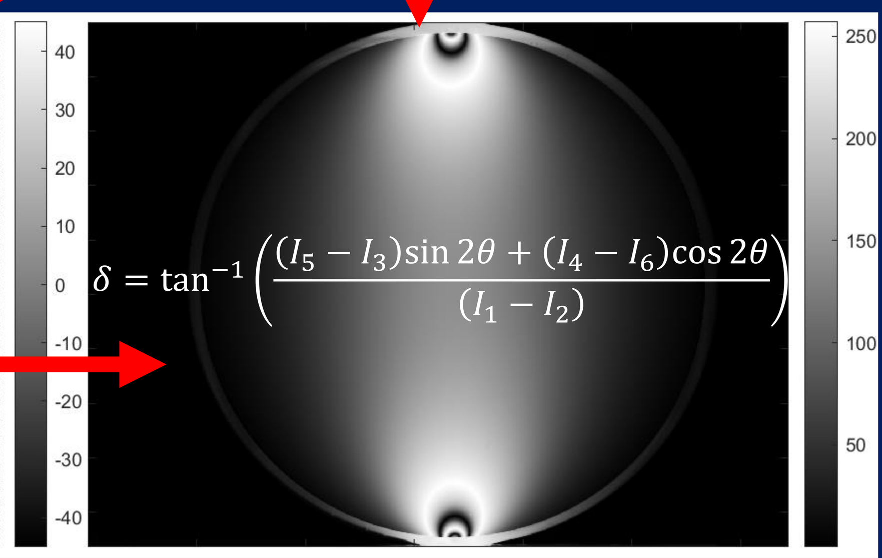
Spatial Resolution:
Reversing the polariscope lead to an increase in spatial resolution from ~0.3mm to ~0.03mm limited by pixel size.



[3]



$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{I_5 - I_3}{I_4 - I_6}\right)$$

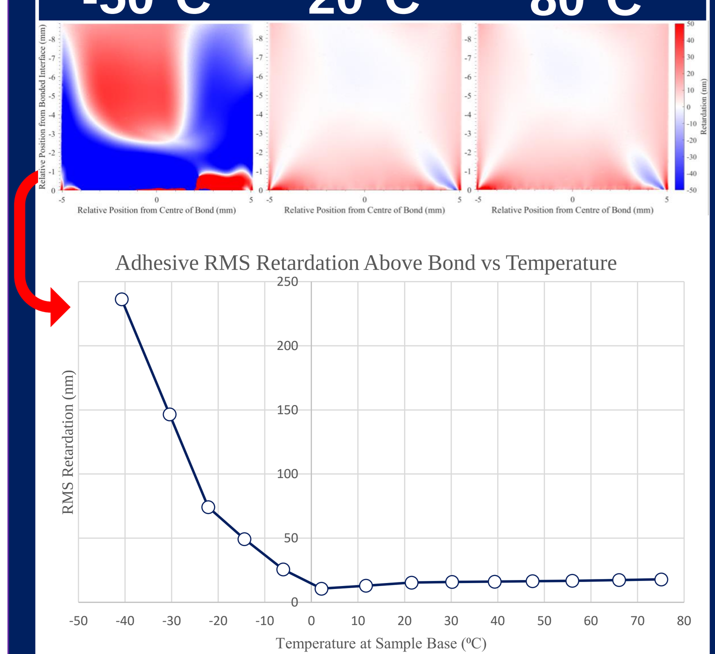


$$\delta = \tan^{-1}\left(\frac{(I_5 - I_3)\sin 2\theta + (I_4 - I_6)\cos 2\theta}{(I_1 - I_2)}\right)$$

Thermal Stress in Bonded Optics

Industry Made Adhesive

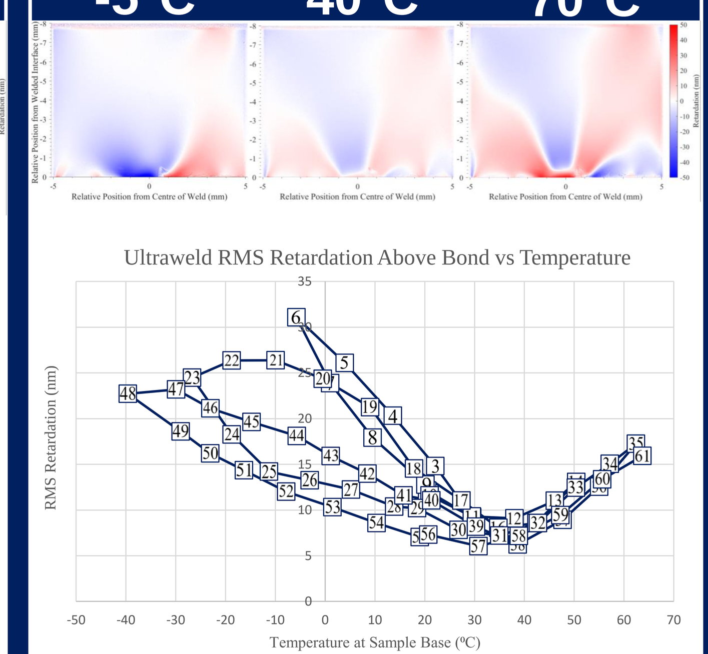
-50°C 20°C 80°C



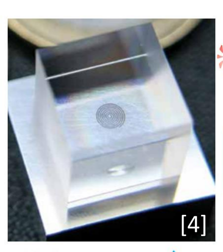
- Industry made adhesives tested different alignment methods
- Results showed high stress at low temperatures
- Most optical adhesives are not characterised over a range of temperatures, which is a problem for aerospace applications

UltraWELD Project

-5°C 40°C 70°C



- UltraWELD sample showed signs of thermal fatigue at low temperature
- Welds may be more resilient if welded in cold environment
- Failure by fatigue is a barrier to industry application



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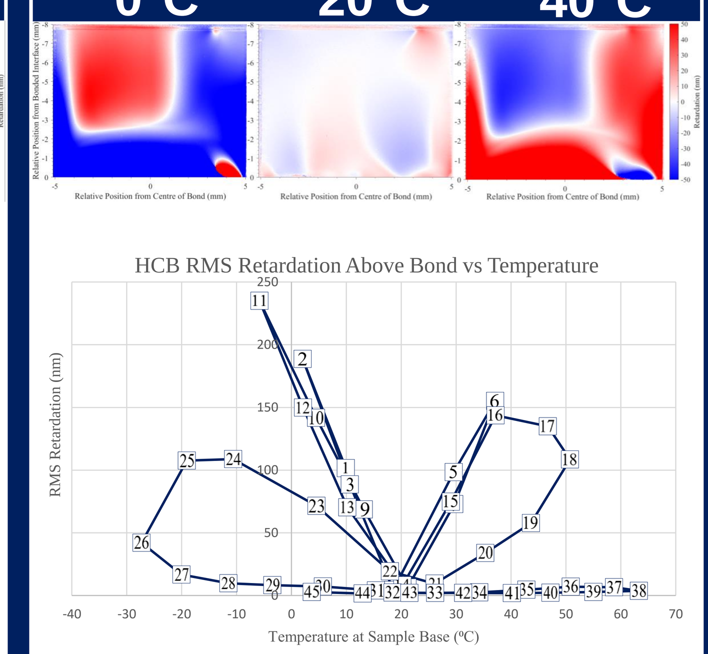
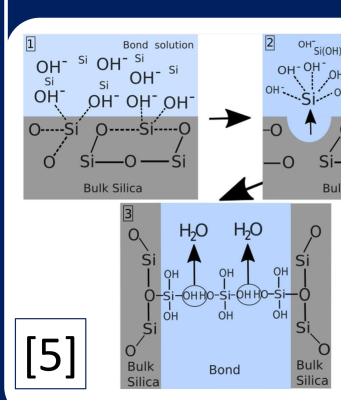
Hydroxide Catalysis (HCB)

0°C 20°C 40°C



- HCB sample not vulnerable to fatigue until ultimate stress failure
- Strength of bond shows unexpectedly high resilience for a glass-metal bond

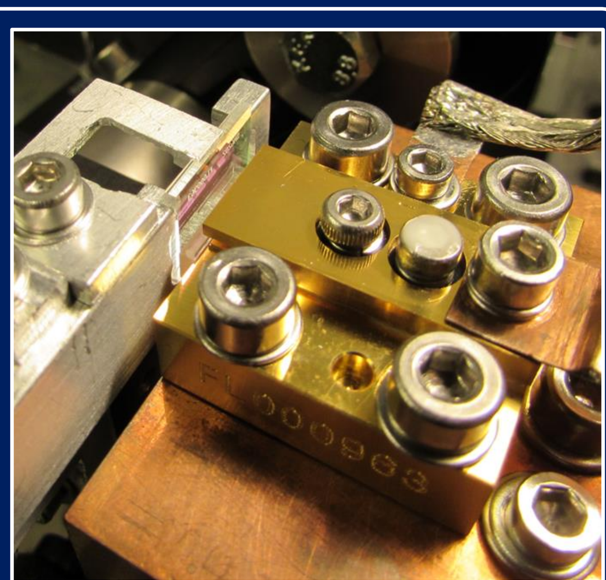


[5]

Key Results and Impact

- Accurate reading and measurement over temperature are impacting understanding of stress in laser industry
- 4 Publications from this project, 3 with new analysis method
- 3 undergraduate dissertations completed, 1 ongoing
- 2 Summer projects undertaken
- Knowledge Transfer Partnership (KTP) in application with PowerPhotonic Ltd.
- RAEng polarisation workshop hosted with industry partners

Outlook:
Stress analysis gives unique insight into failure of bonded optics. New bond methods benefit from this insight, which aids both laser manufacturing and space applications where adhesive outgassing is an issue for optical systems. Good bonding is a foundation of optical systems, and the stress analysis seen here is improving resilience in new bond technologies.



CS mounted laser diode with glued micro-optics [6].

References:
[1] – E. A. Patterson and Z. F. Wang, "Towards full field automated photoelastic analysis of complex components," Strain, vol. 27, p. 49–53 (1991).
[2] – S.N. Hann et al. "Stress Induced Birefringence Analysis in Ultrashort Pulse Laser and Adhesive Bonded Optics ", Proc. SPIE 11540
[3] – Courtesy of Hannah Turner
[4] – M. Dale, "Dissimilar material microwelding gets ready for industry uptake," Laser Systems Europe (9 June 2021).
[5] – M. Phelps, M. et al. "Strength of hydroxide catalysis bonds between sapphire, silicon, and fused silica as a function of time," PHYS. REV., vol. D 98, p. 122003 (2018).
[6] – Courtesy of Dr A.C. Zatarain

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