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Ultrashort pulsed laser welding of co-doped Er,Yb:Phosphate Laser Glass and Nd:YAG Laser Crystals to structural materials for robust mechanical mounting and thermal management

Adrian Dzipalski*[a], Owen McGann[b], Richard M. Carter[a], M. J. Daniel Esser[a], Duncan P. Hand[a].

[a]Heriot-Watt University, Institute of Photonics and Quantum Sciences (IPAQS), Riccarton, Edinburgh, EH144AS.

[b]Glass Technology Services, 9 Churchhill Way, Chapeltown, Sheffield, South Yorkshire, S352PY.

ABSTRACT

Ultrashort pulsed laser welding of dissimilar materials has become an attractive alternative technique to commonly used adhesive bonding for joining optics to metal mounts / assemblies in the manufacturing of optical and laser systems. The laser welding process relies on very high peak intensities from an ultrashort (ps/fs) pulsed laser beam which is tightly focused through a transmissive optical component, providing a focal spot in the vicinity of the optic-metal interface. Non-linear multi photon absorption in the optic and linear absorption in the metal results in a highly confined plasma, surrounded by a localised melt zone that rapidly cools to form a bond. For successful welding, the laser pulse repetition rate must be sufficiently high to provide thermal accumulation, to ensure a localised melt volume (the heat-affected zone, HAZ) surrounding the small plasma. The size of this HAZ is dependent on the laser processing parameters and material combinations used during the process and is typically on the ~100µm scale. As the laser spot translates across the material, this highly localised melt/plasma zone rapidly solidifies behind the beam and forms a strong bond (micro weld) between the two surfaces.

We present our recent results from the ultrashort pulsed laser welding of Er,Yb:Phosphate laser glass and Nd:YAG laser crystals to copper for a combination of mechanical mounting and thermal management (heatsinking) applications in laser systems. Er,Yb:Phosphate glass is a well-known and commonly used active medium for lasers emitting in the 'eye-safe' spectral range from 1.5-1.6µm. Nd:YAG is the most popular lasing media for solid state lasers typically emitting light in the 1.064µm spectral range. We investigate the influence of laser processing parameters such as pulse duration and repetition rate on the resultant welds. Analysis of welded parts includes shear strength and accelerated lifetime tests.

Keywords: Ultra short pulse laser welding, Nd:YAG, Er,Yb:Phosphate, Copper.

1. INTRODUCTION

Ultrashort pulse laser bonding of highly dissimilar materials has been a hot topic in recent decades as a process which offers high bond strength welds and hermetic seals between materials but has been limited to certain material combinations due to the associated problems with the level of mismatch of the thermal expansion coefficients between the two materials. The first demonstration of ultrashort pulse laser welding of transparent materials was by Tamaki (**1**) in 2005 where two plates of silica glass were bonded by means of a femtosecond laser pulse.

Currently, dissimilar materials are bonded using either adhesives, frit bonding, hydroxide catalysis, diffusion bonding and mechanical attachments. Adhesive bonding however, tends to be the most commonly used technique but it has limitations when it comes to its use in high powered optical systems or highly sensitive polarisation dependant optics due to the potential contamination caused during the application of the adhesive (**2**); the degradation which occurs in the adhesive over time with repetitive thermal cycles (**3**); and outgassing(**4**). Outgassing is particularly problematic as the adhesive will tend to shrink over time leading to a change in the alignment of the optical component from its initial setting position and contamination of the optic if the faces get coated with the vapours released from the adhesive. In recent times direct laser welding has become an attractive alternative technique for direct bonding of a range of optical materials to structural

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materials and has demonstrated its industrial relevance when it comes to applications in automation and ease of manufacturing(**5**).

The fundamental operating principle behind the ultrashort pulsed laser welding is that the laser beam propagates through the top optically transparent material, then gets focused at the interface between the transparent optical material and the absorbing structural material. In most cases a high numerical aperture lens is used as the focusing lens but it has been shown that the process can work with a lower numerical aperture beam coming from a galvo-scanner head (6). The linear absorption from the structural material in conjunction with the non-linear optical absorption in the glass then leads to the formation of a plasma between the optical and structural material and this will be composed of both materials. As the plasma cools down, it forms the bond between the two materials. This bond typically measures between fifty to a few hundred microns.

In this work we demonstrate the process development study performed for the bonding of Copper (C106) to Er,Yb:Phosphate laser glass and Nd:YAG laser crystals for a combination of mechanical mounting and thermal management (heatsinking) applications in laser systems. We also report on the relevant ISO certified environmental testing of the manufactured parts.

2. MATERIAL DESCRIPTION

The materials used in these experiments aim to mimic bulk optical components within optical systems (such as gain media in laser systems). Er,Yb:Phosphate glass was chosen as it is a well-known and commonly used active medium for lasers emitting in the 'eye-safe' spectral range from 1.5-1.6µm . Nd:YAG on the other hand is the most popular lasing media for solid state lasers typically emitting light in the 1.064µm spectral range. The Er,Yb:Phosphate glass samples used measure 4.1 × 4.1 × 3mm and the Nd:YAG laser crystals measure 10 × 5 × 5mm. Each cuboid is polished on 2 faces (including the interface that is in contact during clamping). The other four sides are 'ground' as supplied. The surface finish on the 2 polished faces is specified by the supplier as 20:10 scratch-dig and λ/10 for flatness. The metal components used have dimensions of 15mm × 15mm × 5mm, chosen as a standardised base across all the combinations and to ensure consistency and repeatability during the shear strength tests. The copper (C106) coupons were provided by Almond Engineering Ltd, finished with a diamond fly-cut technique. The thermal properties of the materials used during the experiment are summarised in the table below.

Material	**Thermal Conductivity (Wm/K)**	**CTE (µm/K)**	**Δ CTE**
Copper (C106)	**401**	**16.5**	
Er,Yb:Phosphate	**0.85**	**12.4**	**4.6**
Nd:YAG	**11**	**7.8**	**9.2**

Table 1. Thermomechanical properties of materials used in the study.

3. EXPERIMENTAL SETUP

For this study an Amplitude Tangerine HP laser (0-35W, 1030nm, operating at 5ps pulse width and 500kHz rep rate) was used for the experimental work. Previous work has shown that repetition rates lower than 400kHz were unsuitable for this process as there is insufficient thermal accumulation within the structural material. The laser beam produced has a collimated beam output measuring ~3.22mm in the X axis and ~3.12mm in the Y axis with a M^2 value of ~1.2 and a measured beam ellipticity of ~0.96. The beam is passed through a combination of half wave plate and polarising beam splitter to provide a fine control of the laser beam power. The laser beam is controlled by means of an external mechanical shutter (Thorlabs SH05) which turns the beam on and off.

The collimated beam is passed through a telescope and is then guided through a periscope onto a 20mm focal length aspheric lens (Thorlabs LA1074) producing a final numerical aperture of 0.217. A CCD camera is used to monitor the reflections from the top of the optically transparent cuboid to ensure that the top plane of the cuboid is consistent. The experimental setup is shown in the figure below.

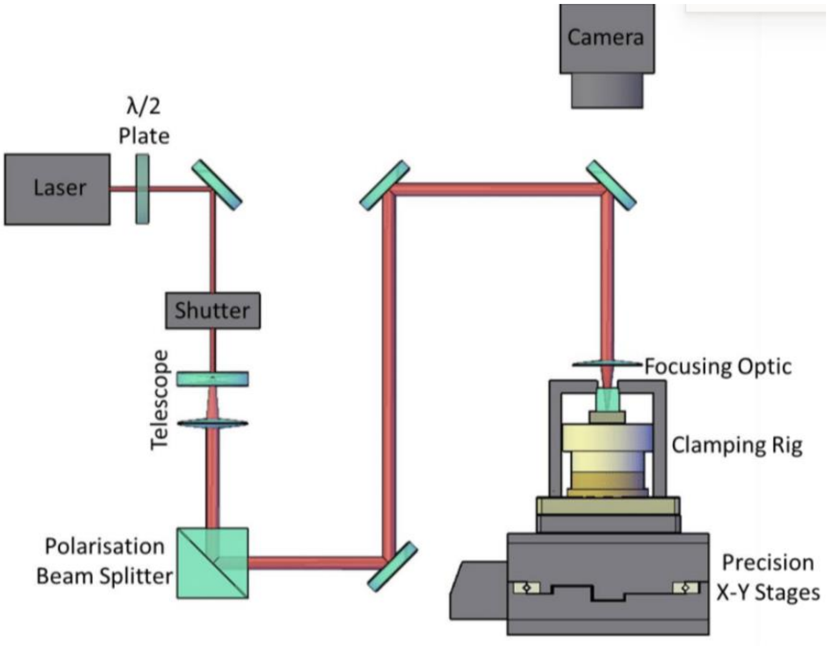


Figure 1. Schematic of laser welding system showing the optical beam path and clamping arrangement.

4. THERMAL CYCLING

Thermal cycling on the laser welded components was carried out in a Binder V66S thermal chamber in accordance with ISO 9022-2:2015. The samples were all tested to severity 6 on the standard where the maximum temperature is 70ºC±2ºC and the minimum temperature is -40ºC±3ºC producing a temperature difference of 110ºC. The temperature ramp was 1ºC/min for heating and cooling and 1 cycle lasted 3.5hrs, repeated 5 times. Upon removal from the thermal chamber all the samples were subjected to a horizontal force of 2.5N applied to the optical component to test for failure. All the samples (10 for each combination) survived the thermal cycling, producing a yield of 100%.

5. RESULTS

A photo showing a sample laser welded component for the two material combinations is shown below. The Er,Yb:Phosphate glass-Copper is shown on the left hand side and the Nd:YAG-Copper is shown on the right hand side.

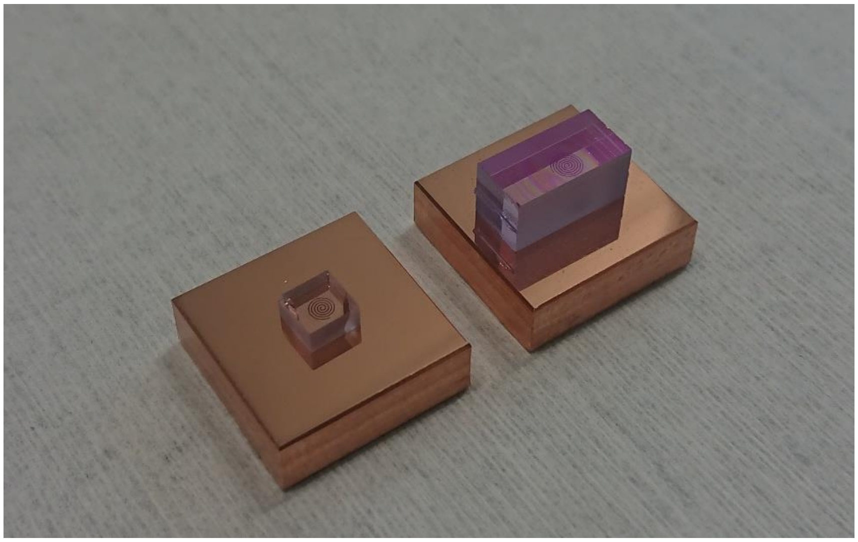


Figure 2. Photograph showing laser welded components.

In the table below, the microscope images show the weld tracks for the two material combinations as seen under brightfield illumination after USP laser welding and after they have undergone thermal cycling.

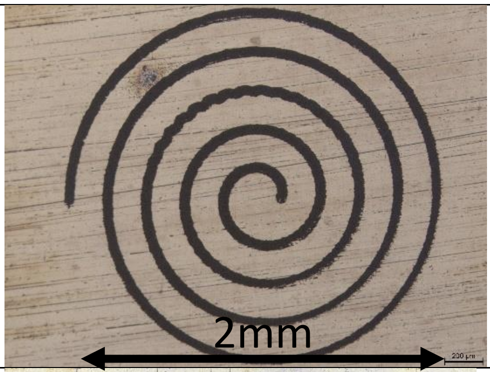
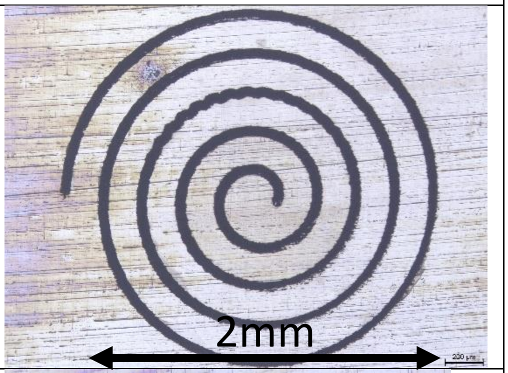
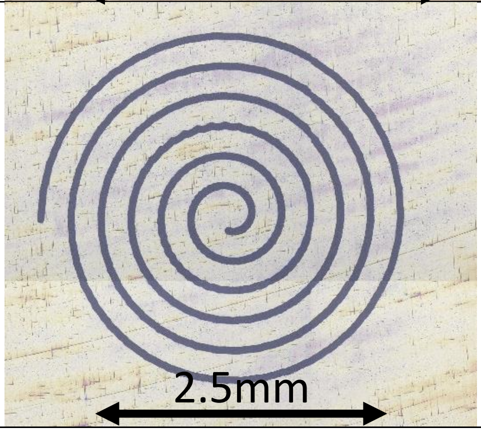
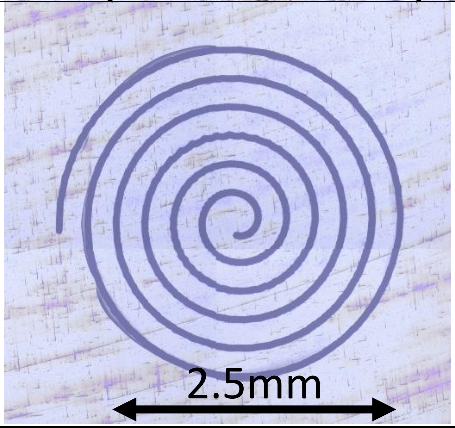
Material Combination	After Laser Welding	After Thermal Cycling
Er,Yb:Phosphate-Copper(C106)		
Nd:YAG-Copper (C106)		

Table 2.Microscope images showing bonds after laser welding and after thermal cycling for the two material combinations.

Thermally induced stress cracks which appear after thermal cycling on the outer periphery of the spiral welding track are due to the CTE mismatch between the welded components. It can be noted that the cracks do not significantly reduce the optical stress induced birefringence in the welded components

CONCLUSIONS

We have successfully demonstrated the ultra-short laser pulse welding of Er,Yb:Phosphate laser glass and Nd:YAG laser crystals to copper (C106) for robust mechanical mounting and heatsinking applications. All the welded components were subjected to ISO standard thermal cycling tests, all the parts survived the severity 6 tests which have a temperature range of 110ºC. Additionally all the components were subjected to a 2.5N force to test for failure after the thermal cycle and they all survived. It can be said that the USP laser welding of these laser gain materials to structural materials is not only possible but reliable and robust process. The thermal conductivity out of the laser welded gain materials, which is critical to laser design, is yet to be tested.

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