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Laser Gain Media to Heat Sink Integration for Improved Thermal Management

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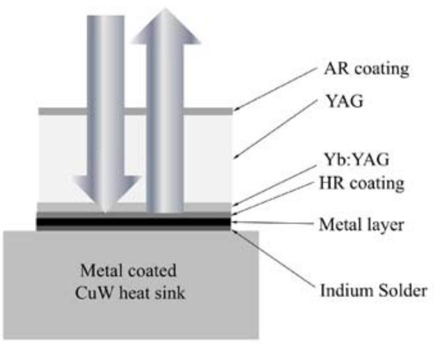

Figure 1a: Typical structure of thin disk laser soldered to CuW heat sink.

As solid state lasers are used at higher powers, demand for better thermal management solutions and more novel mounting schemes will continue to be required. This is particularly true for thin disk lasers [1][2]. Typical mounting techniques for laser gain media to heat sinks involve solder or epoxy layers. A typical example of a soldered thin disk laser is shown in Figure 1a. Both soldering and gluing add bonding layers to the structure. It is essential to have a uniform solder/epoxy layer without voids to prevent hot spots.

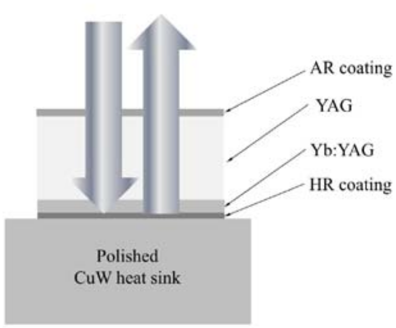

Figure 1b: Structure using CADB® direct bonding to mount the thin disk laser to the CuW heat sink

For the soldering technique, it is difficult to inspect for voids since the solder layer is opaque.

Challenges using epoxy involve shrinkage during curing and relatively poor thermal conductivity of the epoxy layer. In addition, non-uniform bonding layers contribute to wavefront distortion, especially for thin substrates such as for thin disk lasers.

We have investigated a method of directly bonding the laser gain media to a metal/metal alloy heat sink using Precision Photonics' Chemically Activated Direct Bonding (CADB®) technology (Figure 1b). This bonding process results in epoxy-free optical paths that are 100% optically transparent with negligible scattering and absorptive losses at the interfaces. For YAG and similar materials, the process has been proven to offer bond strength performance equivalent to that of bulk. It is thus exceptionally durable, reliable and resistant to changes in laser fluence, temperature, and humidity [3]. Due to the zero bond line thickness, complete conformance is ensured between the two bonded surfaces.

Finite element modeling was performed to compare thermal performance of the thin disk laser structures in Figure 1 a) and b). The resulting thermal distribution is shown in Figure 2 for a 100kW/cm3 uniform heat load in the active Yb:YAG layer. The Yb:YAG active layer was taken to be 200μm thick mounted on a 1mm thick water cooled Copper Tungsten (CuW) heat sink with 10oC water temperature. The diameter of the YAG and CuW were 12mm and 15mm respectively. A 1mm thick undoped YAG cap was on top of the active layer. A 5 μm thick Indium solder layer was included in the structure together with a typical Titanium- Platinum-Gold metallization coating.

The resulting temperature distribution is shown in Figure 2 for a soldered structure. Only a minimal difference in maximum temperature was found between a structure with the indium solder layer and a CADB® bonded structure. As expected, the heating is quite high for such a large heat load with almost 400°C on the top of the structure and approximately 120°C on the top of the CuW heat sink.

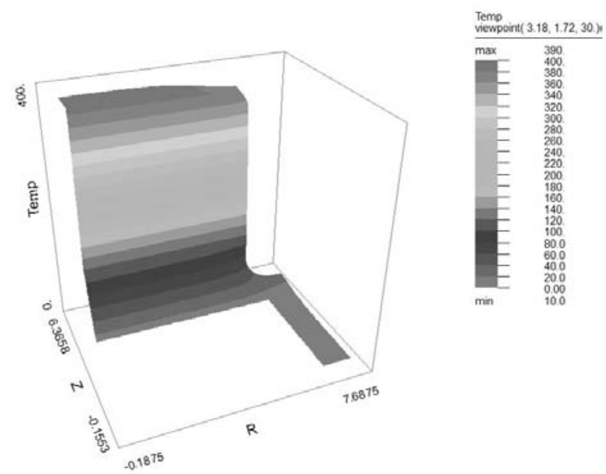

Figure 2: Temperature distribution (°C) calculated using finite element thermal modeling for soldered thin disk laser structure with a 100 kW/cm3 heat load in a 200μm thick Yb:YAG gain layer with a 1mm thick undoped YAG cap soldered to a 1mm thick water cooled CuW heat sink with 10°C water temperature. Z gives the position through the structure in mm from top to bottom (zero is defined to be on the top of the undoped YAG cap) and R is the radius from the center of the structure in mm.

It is clear from the large temperature gradients shown in Figure 2, that matching of thermal expansion between the laser gain media and the heat sink, intermediate layer materials are important. CuW composites are often selected as a heat sink material due to high thermal conductivity and good thermal expansion match to YAG. See Table 1. In particular 90% Tungsten 10% Copper (W90Cu) and 85% Tungsten 15% Copper (W85Cu) composites are used.

Direct bonding requires the surface of the heat sink material and the laser gain structure to conform to each other on an optical scale. This is most readily achieved if both the heat sink and the gain material are polished optically flat. However, the Copper Tungsten composite materials are hard to polish due to the local hardness variation between the Tungsten and the Copper domains resulting in a high surface roughness. To increase our chance of obtaining good metal to YAG bonds, we also included Tantalum metal in this study as it is easier to polish and has a good thermal expansion match to YAG. However, the thermal conductivity is less than a third that of the CuW composites (Table 1).

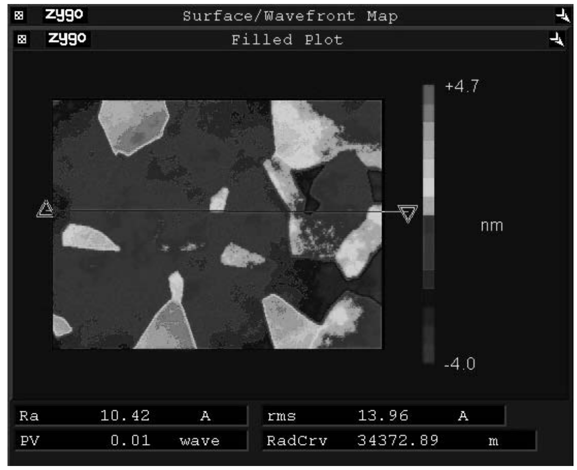

Figure 3a: Small aperture interferogram of polished Tantalum

1" diameter x 0.25" thick W90Cu and Tantalum substrates were polished at Precision Photonics. A RMS surface roughness in the 5-15 Angstrom range was obtained on the Tantalum substrates although a grain structure was observed (Fig. 3a). The CuW substrates experienced differential polishing between the tungsten and copper domains resulting in almost 200 Angstrom RMS surface roughness.

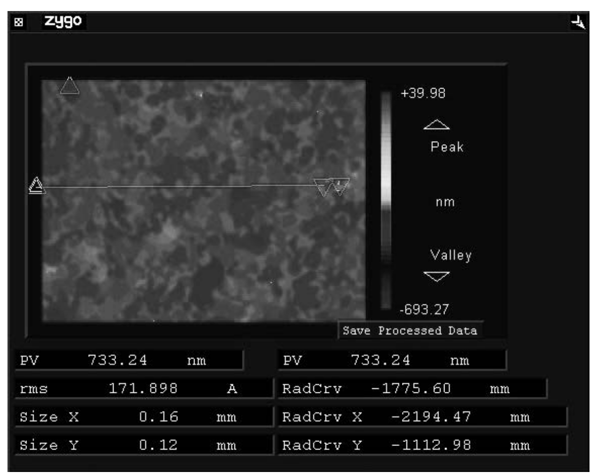

Figure 3a: Typical small aperture interferogram of polished CuW

Figure 3b shows a typical small aperture interferogram of the polished CuW surface. This high surface roughness would normally prevent direct bonding to the substrates. Precision Photonics' CADB® bonding process is able to overcome surface roughness by using a surface treatment process.

For our bonding tests we used laser grade crystalline undoped YAG substrates polished to 3-4 Angstroms RMS surface roughness and laser grade surface quality. The substrates were 1" diameter by 1.1mm thick. We coated some of these substrates with a high reflector coating for 1030nm to simulate the device structure shown in Figure 1b. The coating was deposited using our in house Ion Beam Sputtering (IBS) capabilities. HR coating thickness was 5.8 μm.

Three sample structures were produced: Sample A had an uncoated YAG piece directly bonded to a polished tantalum substrate. Sample B had an uncoated YAG piece bonded to a CuW substrate. Sample C had an HR coated YAG substrate bonded to a CuW substrate with the HR coating at the bond line. Good bonds were obtained on all of the samples with only some delamination in the outer 2-3 mm edge of sample C due to coating stress from the HR coating on the YAG substrate. A photo of sample C is shown in Figure 4. The delaminated area shows up as a faint ring near the edge

Figure 4: CADB® bonded YAG-CuW structure (sample C) with HR coating on interface.

The samples were temperature cycled to over 150°C. This resulted in some small voids forming in the bond line of the tantalum sample, but no changes to the CuW samples. The void formation is thought to be due to out gassing from the tantalum surface.

Due to the multiple surfaces involved, it was difficult to get a good measurement of the surface figure of the bonded part. Sample C measured below $\lambda/2$ over the central 0.5", while measurements on Sample A and B did not yield useful results. The YAG substrates had under $\lambda/10$ transmitted wave front distortion and were thin enough to conform to the metal substrate surface. Most of the distortion originated from the edge roll during the polishing of the CuW substrates and can be improved with a better polishing process.

We have demonstrated that it is possible to use Precision Photonics' CADB® bonding process to directly bond coated and uncoated YAG to CuW and Tantalum metal substrates. More work remains to refine the process for optimum bond strength and to fully characterize thermal performance of the structure. It will also be interesting to investigate if the bond strength is sufficient for post processing such as thinning down the YAG substrate to final thickness after the substrate is bonded to the CuW.

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