Novel Technique for Producing Over-sized Laser Gain Media in High Fluence Applications

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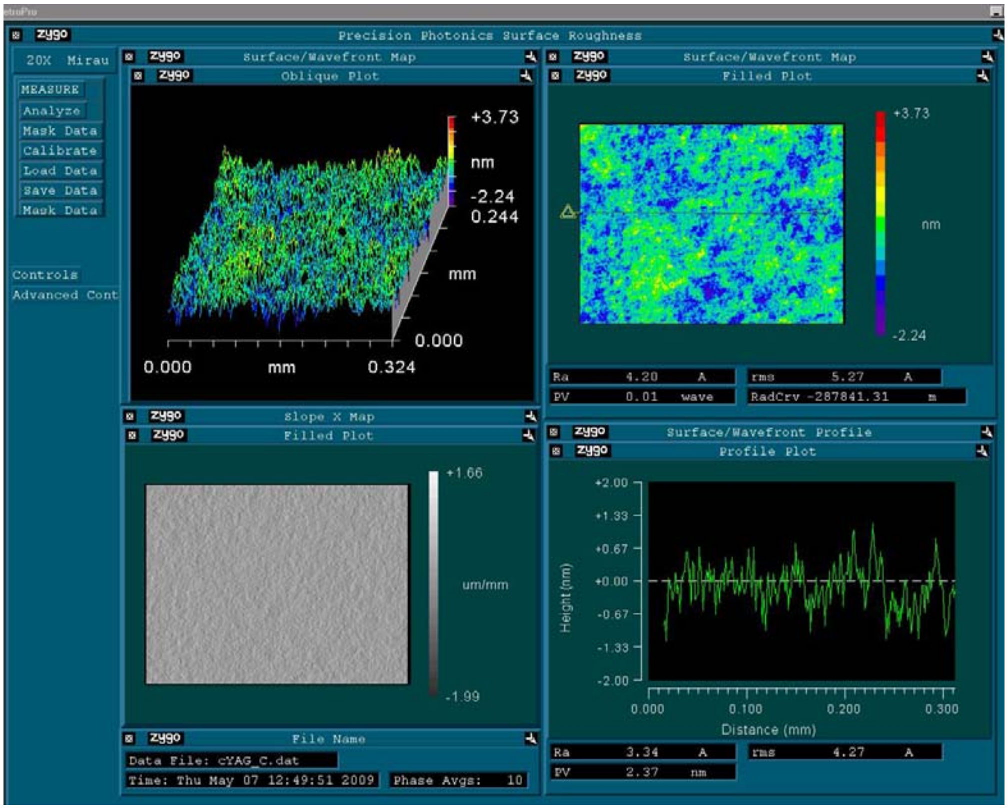
As the demand for higher power solid state lasers increases, there is a growing need for larger gain media than what is currently available from crystal and ceramic material growers. We present a method for bonding laser gain media and other optical materials into monolithic bulk pieces larger than what is offered commercially.

The Chemically Activated Direct Bonding™ (CADB®) process can be used to bond individual crystals or ceramics into single pieces larger than what can be grown with conventional methods. This allows for more design flexibility and larger form factors. The CADB technology results in epoxy-free optical paths that are 100% optically transparent with negligible scattering and absorptive losses at the interfaces. This patent pending process offers bond performance near that of the bulk materials being bonded and thus is exceptionally durable, reliable, and resistant to changes in laser fluence, temperature, and humidity.

The CADB process has been previously shown to give near bulk strength in laser gain materials such as YAG and phosphate glass [1]. In this work, 3mm x 3mm x 6mm samples both with and without a bond interface present at the center were broken on a small load cell set-up. A summary of this data is shown in Table 1.

	Ceramic YAG	**Qx/Er Phosphate Glass**
Bulk Material	15.1 kg	2.3kg
CADB Bonded	12.6kg	1.9kg
% of bulk strength	83%	83%

Table 1. CADB bonded and bulk material strength for Ceramic YAG and Qx/Er Phosphate glass [1].



Ra 4.20 A
rms 5.27 A
PV 0.01 wave
RadCrv -287841.31 m

Data File: cYAG_C.dat
Time: Thu May 07 12:49:51 2009
Phase Avgs: 10

Ra 3.34 A
rms 4.27 A
PV 2.37 nm

Figure 1. Surface figure of <0.1 waves and surface roughness <4.2 Angstroms on YAG as polished at Precision Photonics

With the resultant mechanical strength of this process technology understood, it next becomes important to understand the laser fluence handling capabilities (LDT); the end goal being to produce tiled or stack assemblies of crystals or ceramics that behave like a single monolithic element. Bonded and bulk material samples were prepared of dimensions 4.5mm x 14mmx 10mm. In the case of the bonded samples they were created by polishing two separate 2.25mm x14mm x 10mm samples and bonding them together with the CADB process. All broad surfaces on both the bulk and bonded samples were polished to a very high "laser quality" finish. Samples were prepared of both bulk and bonded ceramic and single crystal YAG. We achieved similar results when polishing single crystal or ceramic YAG and examples of the surface roughness and flatness of these surfaces is shown in Figure 1.

Samples were then submitted for laser damage testing at Big Sky Laser Technologies. The testing parameters were 1064 nm, 20ns pulse duration, 20 Hz rep rate, and a 0.5mm $1/e^2$ beam diameter. 100 sites were tested at each fluence level and 200 shots were fired at each site. Two samples of each type were tested. A summary of results is provided in Table 2 below.

	Ceramic YAG (bulk)	**Ceramic YAG (CADB ®)**	**Xtal YAG (bulk)**	**Xtal YAG (CADB®)**	**Ceramic YAG (CADB® - B)**
Sample #1	9.1	4.5	3.6	7.6	7.6
Sample #2	7.3	4.4	5.4	9.4	4.4
Average LDT	8.2	4.5	4.5	8.5	6.0
% of Bulk LDT	100%	55%	100%	>100%	73%

Table 2. Laser Damage Values (J/cm^2) for bonded and bulk YAG samples.

It should be noted that the damage testing results indicated some defect sites present in the bulk material that may have been giving artificially low results. For instance, actual data from one of the crystalline YAG bulk samples is shown in Figure 2 below. As can be seen in the bulk example, there is a small percentage of damage sites at the lower fluences, but they do not follow a typical trend line even dipping back to no damage whatsoever at 12.7 J/cm^2. This would indicate that the damage is caused by a small scattering of point defects (or possible surface cleaning) and not actual bulk damage. An example of LDT data from one of the bonded ceramic YAG samples is shown in Figure 3. The bonded sample shows a more expected trend line with a more easily definable damage point.

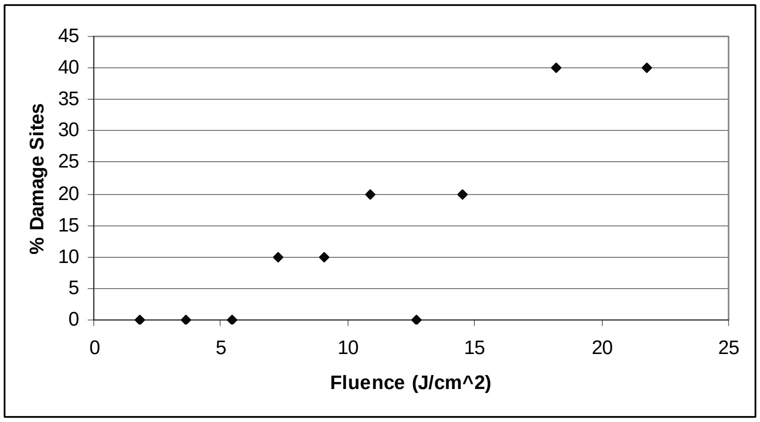


Figure 2. Measured LDT data from crystalline YAG bulk sample #2

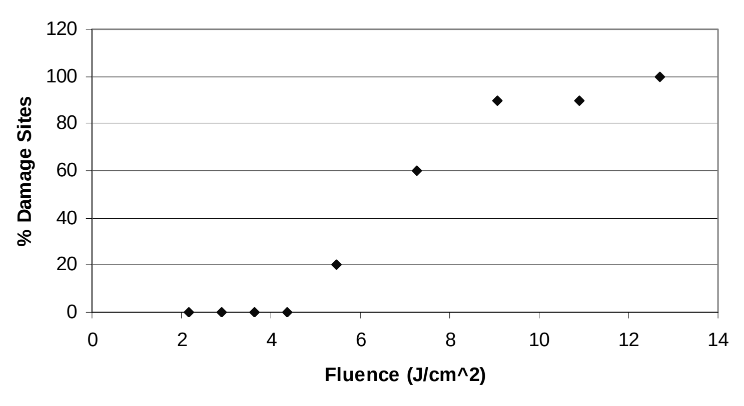


Figure 3. Measured LDT data from ceramic YAG bonded sample #1

A more practical interpretation of the LDT data shown in Figure 2 would lead to moving the predicted inflection point out to approximately 10 J/cm^2 for this sample, versus the 5.4 J/cm^2 shown in Table #1. A revised table of LDT data using this type of interpretation is shown in Table 3.

	Ceramic YAG (bulk)	**Ceramic YAG (CADB ®)**	**Xtal YAG (bulk)**	**Xtal YAG (CADB)**	**Ceramic YAG (CADB - B)**
Sample #1	10	4.5	9	8	7.6
Sample #2	13	4.4	10	9.4	7
Average LDT	11.5	4.5	9.5	8.5	7.3
% of Bulk LDT	100%	39%	100%	89%	63%

Table 3. Laser Damage Values (J/cm^2) for bonded and bulk YAG samples, using “practical” LDT determination.

Of particular interest are the relative LDT values between the CADB® bonded and bulk material. For the crystalline material, the bonded LDT is 89% of the bulk value, while for the ceramic material it is notably lower at 39% for our standard CADB process. This is likely due to some peculiarity in the properties of the ceramic material that may cause more sub-surface damage in polishing or the bonding process. We have also noted qualitative differences in the damage zones (size of pits and extent/shape of surrounding damage) between the single crystal and ceramic YAG samples. See Figures 4 and 5. This variability in amount and type of damage between the crystalline and ceramic YAG is likely to depend on the details of the material structure. Also of note is that the bulk samples all exhibited surface damage sites in addition to the bulk material, while none of the bonded samples showed any surface damage. This may be due to the more aggressive cleaning process the bonded samples went through during bonding.

To understand these differences and find potential solutions will require further research. In the meantime, Precision Photonics has developed a revised bonding process (indicated as CADB-B in the table) for ceramic materials such as YAG and spinel that shows a notable improvement in laser damage threshold relative to the original process (63% of the bulk value).

It should also be noted that the absolute values measured during these tests are significantly lower than those previously published [2]. The authors feel the mostly likely cause for this is a self-focusing effect due to the much larger beam being used in these tests versus [2]. This could result in a much smaller spot, and corresponding fluence, at the bond interface or within the bulk of the material than at the surface of the part. In any case, the most relevant data from this experiment are the relative values of the bonded to bulk material. For a detailed explanation of self-focusing, see [3].

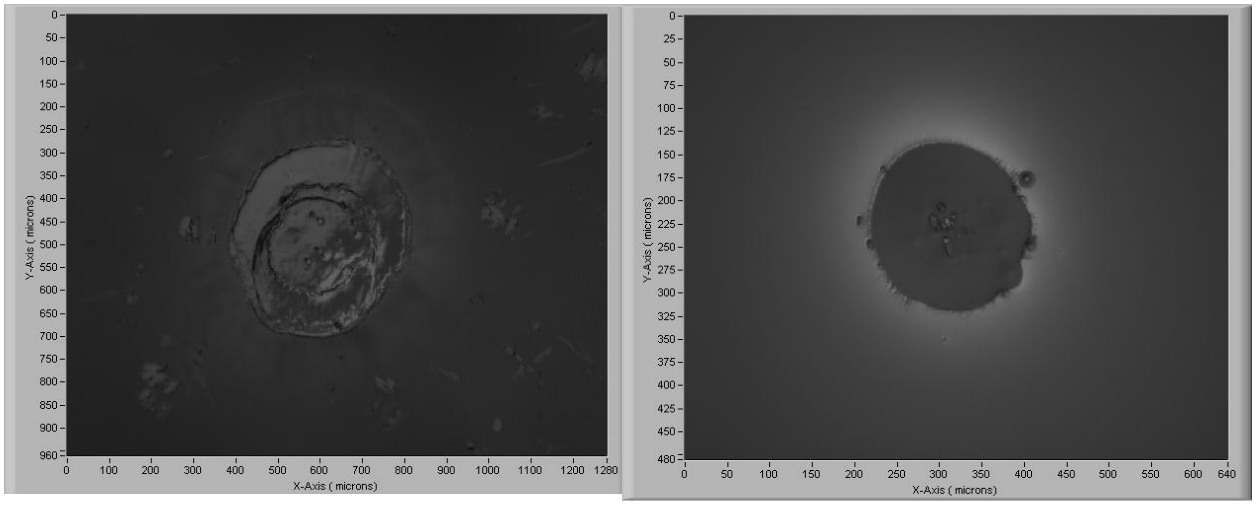


Figure 4. Bulk (left) and CADB® bonded (right) damage site photos on single crystal YAG. Bulk damage site is approximately 400um in diameter and the bonded damage site is approximately 200um in diameter.

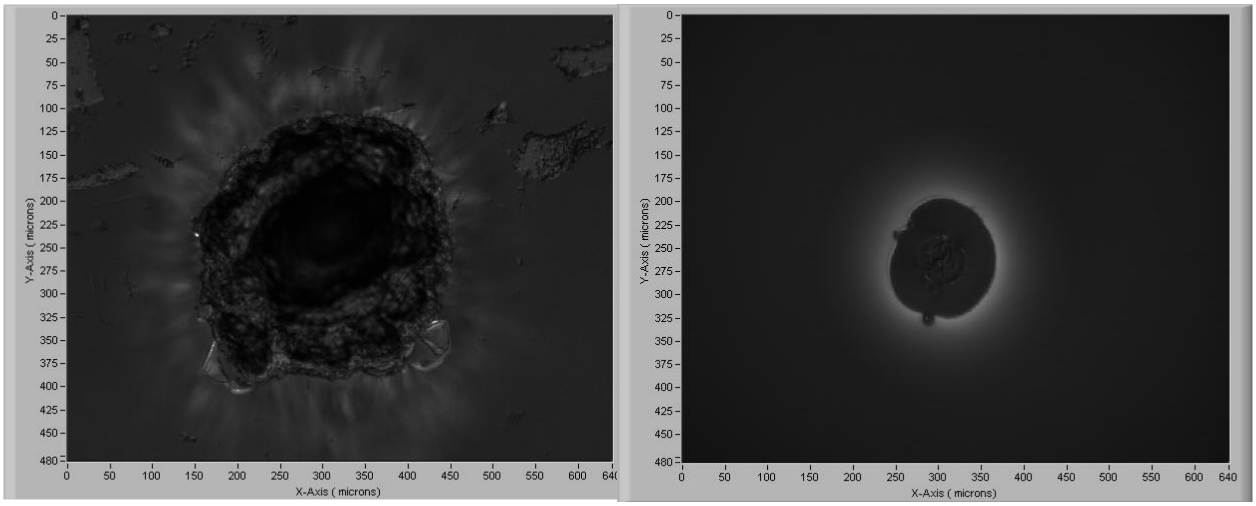


Figure 5. Bulk (left) and CADB® bonded (right) damage site photos on ceramic YAG. Bulk damage site is approximately 290um in diameter and the bonded damage site is approximately 135um in diameter.

Conclusion

The CADB bonding process has been proven to be an excellent technique for bonding individual material pieces into a larger monolithic piece. Mechanical strength and laser fluence handling capabilities have been tested to perform near that of the bulk materials. To date, the authors have bonded areas as large as 200mm^2 and feel that this process can be scaled to larger sizes limited only by one’s polishing capabilities. It also has been observed that different materials require modifications to the polishing and bonding process to account for individual properties, and variants of the standard CADB process have now been developed for single crystal, ceramic, and glass materials. Further research will continue to be done in this area as new host and heat sink materials are developed.

References

[1] Traggis, N., Claussen, N., “Epoxy Free Bonding for High Performance Lasers”, 11th Annual Directed Energy Symposium Proceedings, Directed Energy Professional Society (2008).

[2] Bisson, J. et al, "Laser Damage Threshold of Ceramic YAG," Japanese Journal of Applied Physics, Vol 42, pp 1025-1027(2003).

[3] Siegman, A.E., “Lasers”, University Science Books, pp. 380-382, (1986).