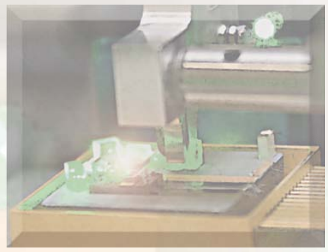
Manufacturing of ultra-robust solid state lasers using high temperature curing processes



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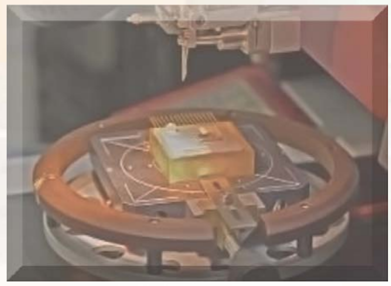

Industrial expectations on the performance of lasers for today's high-tech diagnostic instruments continue to grow stronger and stronger. Typically compact, continuous wave (CW), diode pumped solid state lasers (DPSSLs) are integrated into such systems, often replacing legacy gas lasers such as Argon ion, or lamp pumped systems. The lasers may run around the clock in analytical and diagnostic instruments that are gathering data in all aspects of life science research, such as in DNA sequencing, cancer research and live cell imaging applications.

1 Motivation

DNA sequencing instruments are often run for days at a time, generating data on a single genome sequence, and any problem with the laser source could potentially risk invalidating the results. This applies significant pressure on the manufacturers of DPSS lasers to produce lasers which are essentially fault free over years of continual use. In theory, this may appear trivial but in practice it is extremely demanding. A laser is a very delicate and typically sensitive device, and its performance may degrade severely as a result of optical surface contamination or a µm or sub-mrad mechanical displacement of a cavity component. This puts extremely high demands on the design, the choice of materials, the cleanliness and the method for fixation of the cavity components in the manufacturing process.

Solid state lasers are known to offer a much extended lifetime as compared to gas lasers, thanks to the stability of the lasing medium. In addition, solid state lasers are more compact, energy efficient and silent when compared with gas lasers. However, these advantages can not be realised in practice if the laser assembly in itself is neither extremely stable over time nor insensitive to thermal and mechanical variations.

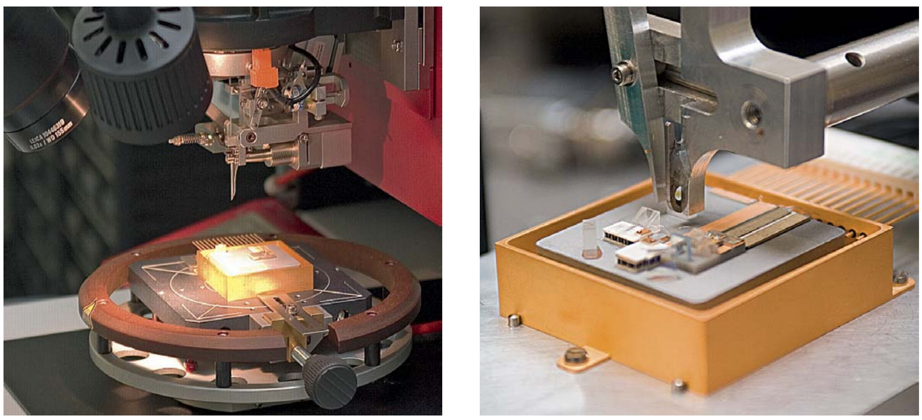

Figure 1: Laser pre-assembly (left) and active alignment of optical components with µm precision (right), prior to permanent fixation using high temperature curing technology

2 High temperature curing

The introduction of a high temperature curing process for the assembly and fixation of cavity components provides a solution to this challenge and has shown to result in a new level of reliability for high performance solid state lasers. The technology is based on building the lasers into a hermetically sealed sub-package in a planar configuration and without mechanical sub-mounts. The material and design of each component in the architecture must be carefully chosen for extremely high overall thermo-mechanical stability. This is foremost done through matching the coefficients of thermal expansion (CTE) of all parts involved to each other. As a result, the design is so thermo-mechanically stable that the whole laser can be heated to 150°C, for several hours and in multiple steps, as part of the manufacturing process, without the laser cavity going out of alignment or any damage being caused.

This capability of the design has enabled the use of a new advanced type of adhesive for the fixation of cavity components that cures at high temperatures, instead of conventional methods using UV light curing adhesives. Thermal curing yields a much stiffer and more reliable fixation joint, free from outgassing and the long-term drifts sometimes associated with the after-curing of UV light curing adhesives.

Although this new manufacturing method is inherently more complex and technically more advanced than other techniques, from a manufacturing perspective the production line is more streamlined and suitable for automation (**figure 1**), which in turn

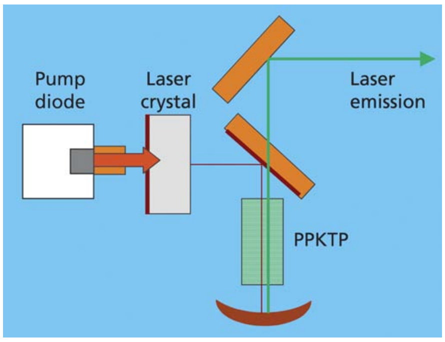

Figure 2: Schematic set-up of a diode pumped solid state laser featuring intra-cavity frequency conversion

decreases the manufacturing time, increases the yield and reduces the production costs. Also, it is considerably easier to quickly change laser models, i.e. wavelengths and output powers during manufacturing, with minimal disruption to the production line, as well as to introduce new lasers (with other wavelengths and power levels) based on the same platform, without the need to change tools or the manufacturing process.

The assembly process starts with the fixation of the pump diode laser with its special collimation and focusing optics. Next follows the alignment of the laser crystal for coherent infrared radiation emission, the separate curved mirror for TEM_{00} beam profile generation, the PPKTP crystal (periodically poled potassium titanyl phosphate, $KTiOPO_4$) for infrared to visible light frequency conversion, as well as a number of other components inside and outside the actual laser cavity (**figure 2**). Between several of these alignment steps, during which the position of the components are temporarily secured using UV-hardening of the adhesives, the pre-assembled laser is heated in a special oven to secure a complete temperature curing.

To protect the delicate optical surfaces from contaminations and secure the laser performance over long periods, also when used outside controlled laboratory environments, the last step in the laser assembly process is to hermetically seal the capsule. This is achieved through laser welding in a nitrogen atmosphere, thereby also eliminating the risk for humidity inside the laser, when it is exposed to temperatures below the dew point.

3 Properties

Lasers built using this new technology feature an improved intensity stability and lower noise, due to the higher alignment precision and more rigid fixation than DPSS lasers from conventional manufacturing processes. The most striking difference, though, is in terms of the robustness and much reduced sensitivity on varying external conditions. The lasers can e.g. be exposed to extreme temperatures (>100°C), and are virtually insensitive to changes in pressure and humidity [1]. External tests at the Swedish Standards Institute (SP Technical Research Institute) confirmed that the lasers can withstand multiple 60 g (8 ms) shocks while in operation [2] with no performance degradation. Additional transport tests for vibration [3], bump tests [4], and free fall tests [5] also showed no impact on the lasers' performance. An example of the power stability and noise of such DPSS lasers is shown in **figure 3**.

To test the influences from varying ambient temperatures, the lasers have been mounted on a platform that was temperature cycled between 20 and 50°C. The data in **figure 4** shows that the noise performance, both rms and peak-to-peak, is virtually unaffected by temperature changes. In addition, to make the tests even tougher, the laser was turned on and off for intervals of 1 hour.

Due to the thermal matching and choice of materials that feature low coefficients of thermal expansion, changing the ambient temperature only leads to small expansions or contractions of the laser platform and thus only to tiny changes to the cavity elements' relative positions, as well as minimal differences typically <6 µrad/°C in the beam pointing (**figure 5**).

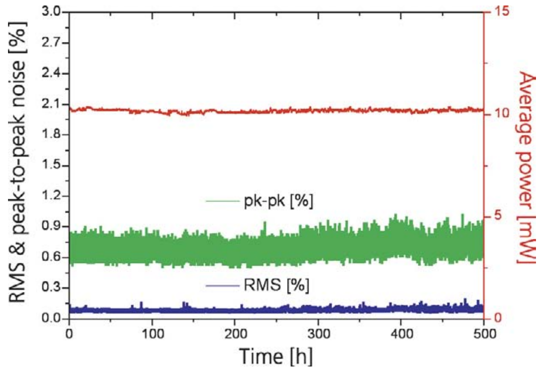

Figure 3: Typical noise performance and power stability of high temperature cured lasers

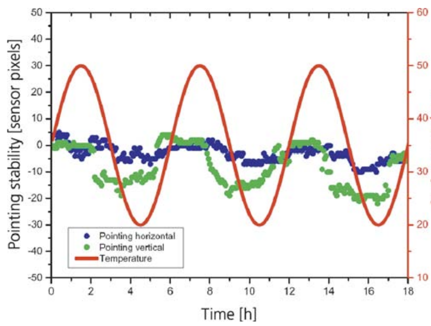

Figure 5: Data for a laser manufactured using high temperature curing showing beam pointing stability of <4 µrad/°C

4 Longevity

Another direct consequence of the new manufacturing technique is that even in 24/7 operation, the lifetime of the lasers is approaching the lifetime of the pump diode laser itself, thus, meeting the expectations of industrial high tech equipment manufactures.

Typical lifetime data for lasers manufactured using high temperature curing can so far only be presented for up to 25 000 hours of operation (**figure 6**), since this manufacturing process is still relatively

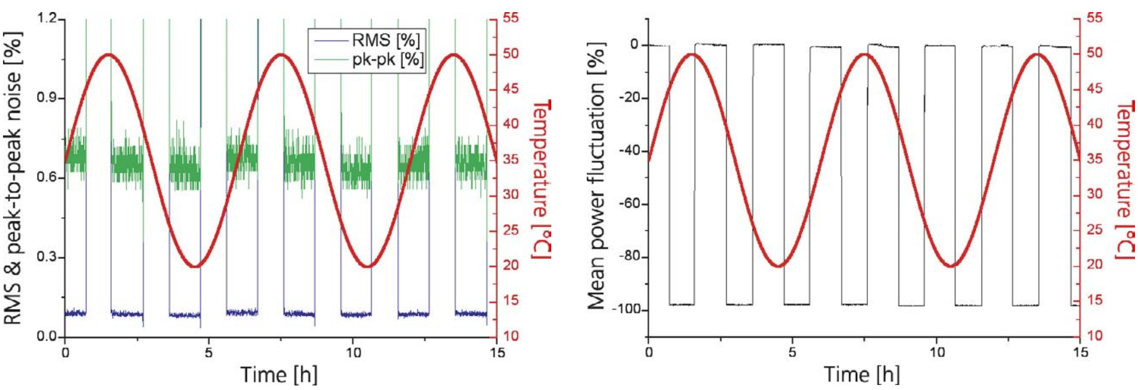

Figure 4: Data for lasers manufactured using high temperature curing showing rms and pk-pk noise as well as power stability for temperature cycling 20–50°C, whilst also turning the laser on and off

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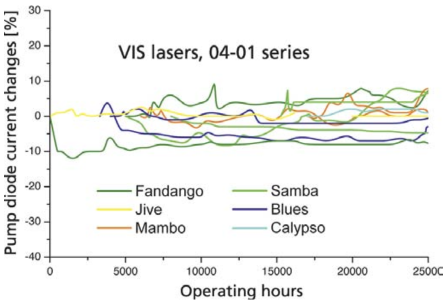

Figure 6: Typical lifetime data for lasers manufactured using high temperature curing

new (the first lasers of that kind were made in 2007). This data represents the relative change of the pump diode current required to maintain constant laser power over time. This current is relatively constant, considering the test conditions in a non-environmentally-controlled room. Most importantly, the pump current shows no systematic increase, which could indicate a degradation and loss of laser power. Note the different starting points for different lasers, the first of them having exceeded 25 000 hours without any degradation.

5 Conclusion

The presented high temperature curing technology for the manufacturing of DPSS lasers, with more than 1200 units in the field already, has proven to provide reliable sources for today's demanding laser applications especially in life sciences.

Literature:

[1] *www.youtube.com/watch?v=u58Q_3pN3cs*, Cooking a Cobolt laser
[2] IEC 60068-2-27
[3] IEC 60068-2-64, 5–200 Hz, 90 min
[4] IEC 60068-2-29, 180 m/s^2, 6 ms, 200 bumps
[5] IEC 60068-2-32, concrete or steel, 1 m, 6 falls

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