Synthetic diamond as an intracavity heatspreader in compact solid-state lasers

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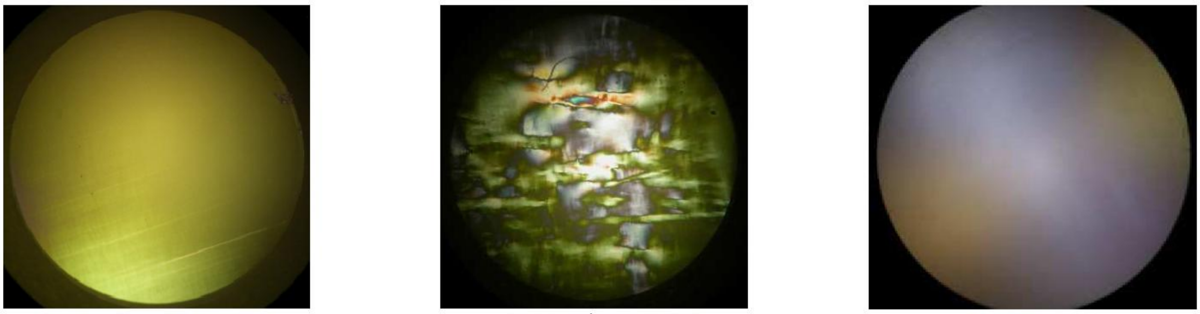
Efficient thermal management is a prerequisite for power scaling in most diode-pumped solid-state lasers. This is particularly true where the laser must be compact and rugged, in remote gas-sensing and avionics for example. In this paper, we will present a study of the use of intracavity diamond – particularly synthetic single crystal diamond – for thermal management in compact lasers. We will discuss finite element thermal modelling of compact diode-pumped disk lasers, both with doped-dielectric and semiconductor gain media. In addition we will present an experimental comparison between synthetic diamond types: chemical vapour deposition (CVD) grown single crystal diamond and high-temperature, high-pressure grown single crystal diamond. To provide a base-line for comparison, results from the use of single crystal natural diamond will also be presented. Particular attention will be paid to the birefringence of the various samples, as this has proven to be of considerable importance for laser operation [1].

Although diamond is in principle an isotropic material, it can, in practice, have significant birefringence. Figure 1 shows polarisation micrographs of (a) a natural diamond sample with very small and uniform birefringence, (b) a CVD-grown single crystal synthetic diamond exhibiting considerable non-uniformity in birefringence, and (c) a high-temperature high-pressure grown diamond sample with small, uniform birefringence. Single point polarimetric measurements indicate that any birefringence in the natural diamond sample was $<2\%$ of full wave retardation at 1064nm. By contrast, this figure varied from $<2\%$ to 16% for the CVD diamond sample, with an associated variation in the orientation of the birefringence [1]. Work undertaken for this paper indicates that the birefringence in the high-pressure high-temperature grown material is $<3\%$ of a full wave retardation at 1064nm and varies very little from point to point. (It should be noted that not all natural diamond samples were found to have the low birefringence illustrated in figure 1a; there was considerable batch-to-batch variability and this will be discussed in the presentation.)



(a) (b) (c)

Fig. 1: Polarisation micrographs of diamond samples: (a) natural, (b) CVD, (c) high-temperature high-pressure grown.

All three diamond samples have been successfully bonded to laser gain materials using liquid-capillary bonding [2]. Low threshold laser oscillation has been demonstrated, again with all three samples. The effect that the different diamond samples have on the output polarisation under laser operation will be discussed in detail. Considerable variation is observed between diamond types and, in the case of natural diamond, from batch to batch. Use with both doped-dielectric and semiconductor gain media will be discussed.

Diamond can significantly improve the thermal management of compact solid-state lasers. As the finite-element and experimental work we will present demonstrates, this is particularly true for intracavity use of diamond. However, care must then be taken to assess – and if necessary compensate for – the significant birefringence observed in some diamond samples. This is particularly problematic where there is a spatial variation in the birefringence. Nonetheless, we demonstrate that high efficiency laser oscillation can be achieved, even in a cavity with a polarisation dependent loss: either by selection of low birefringence diamond, or by careful mitigation of the effects of the birefringence. Thus, the unique thermal management potential of diamond can be harnessed to help power scale compact lasers; the increasing quality of synthetic single crystal diamond is likely to make this increasingly economic.

[1] F. van Loon, A. J. Kemp, A. J. Maclean, S. Calvez, J.-M. Hopkins, J. E. Hastie, M. D. Dawson, and D. Burns, "Intracavity diamond heatspreaders in lasers: the effects of birefringence," *Opt. Exp.* **14** 9250-9260 (2006).

[2] Z. L. Liau, "Semiconductor wafer bonding via liquid capillarity," *App. Phys. Lett.*, **77** 651-653 (2000).