Expansion-matched heat sinks made by micrometal injection molding

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A new approach to producing heat sinks enables complex geometries, cost-effectiveness, and the opportunity to recycle excess material back into the production process.

Laser bars (arrays of multiple parallel emitters on a semiconductor substrate) are on the verge of becoming a consumer product. According to estimates, within two to three years, more than a million laser bars will be needed to meet the demands of industry, for example, in materials processing and medical applications. If that happens, it will lead to a significant drop in price for high-power diode lasers. Interest has also been growing in using thermal-expansion-matched microchannel heat sinks with very high cooling performance to increase the reliability of high-power diode-laser bars. One new approach to producing heat sinks uses micrometal injection molding (μ-MIM). Unlike conventional heat sinks, which are made of copper, these devices combine tungsten—a material with a very low coefficient of thermal expansion (CTE) and moderate thermal conductivity—with copper, which has moderate CTE and high thermal conductivity (>400 W/mK). Manufacturing heat sinks by μ-MIM enables economical mass production of complex microscale near-net-shape parts. Especially in runs of over 10,000, the μ-MIM process reduces the cost per part considerably (up to 70%). μ-MIM offers several other significant advantages, such as the possibility of producing structurally and geometrically complex composite parts with desired mechanical and thermal properties. The copper-tungsten heat sinks have a gallium arsenide (GaAs)-matched CTE, combined with high thermal conductivity. Yet another advantage of μ-MIM is that the needed green bodies—molded components—of the heat sink can be joined together in a cosintering process.

In the field of expansion-matched heat sinks, high power means a thermal load of more than 600 W/m² underneath the diode-laser bar. The continuously increasing output power is achieved by a similarly increasing resonator length and, consequently, the expanding footprint area of the laser bar. This ensures that thermal loads do not increase as wall-plug efficiency simultaneously rises to over 55%. Effective cooling requires water-cooled active sinks.

We fabricated heat sinks using a material composition of tungsten-copper 80/20% by weight. This composition shows a CTE of 8.8 parts per million (ppm)/K, slightly above the required 6.5 ppm/K of GaAs. With μ-MIM, it is possible to create the required flow-channel structures. Powders with an average diameter of only 5 μm are used for metal-powder injection molding. These powders allow high contour accuracy and good mixing of both constituents. Densities of more than 98% are achieved following sintering. The sprue material is recycled and reused, which makes μ-MIM environmentally friendly (see Figure 1).

In cosintering, individual green bodies are positioned one on top of the other and joined inside a kiln at high temperatures (>800°C), with no need for additional joining steps. For our purposes, the joining material is copper. As an alternative to μ-MIM, we used silver diffusion soldering. Here, presintered heat sinks

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are silver coated (which constitutes one additional processing step), braced together, and then also joined together inside a kiln at temperatures $>500^\circ$C (see Figure 2). As is generally the case with injection molding, it can be assumed that the relatively high cost of tools for manufacturing heat sinks using $\mu$-MIM will drop with an increasing number of units. To first approximation, the price per heat sink should be under 20 Euros (~$27) for a total of 10,000 manufactured units.

Test results have shown that thermal design of the heat sinks with a minimal pressure drop ensures a high flow rate. The aim is thermal resistance $<0.5$K/W. The units we manufactured using the second joining process show no significant change in flow rate after 1000h of extended testing. Only after 2400h during a long-term test under full load with a constant pressure drop of 3bar did we encounter a leak, located in the joining zone between the sintered parts. Prior to the long-term test, we had identified thin areas of pure copper under a microscope, and these turned out to be the culprit. We plan to modify the heat-sink design to prevent formation of pure copper areas in the water-cooled section of the device.

In a follow-up project, we will investigate the possibility of manufacturing a heat sink consisting of only two parts using $\mu$-MIM. We are especially interested in knowing whether relocating the joining zone away from the water-cooled area can improve the sink’s lifespan. Cosintering will still be the joining process of choice. In summary, the advantages of the $\mu$-MIM process are its amenability to complex geometries, its cost-effectiveness, and the opportunity to recycle excess material back into the production process. The advantages of $\mu$-MIM-manufactured heat sinks themselves are very-high-performance cooling and a high life expectancy with respect to erosion and corrosion.

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