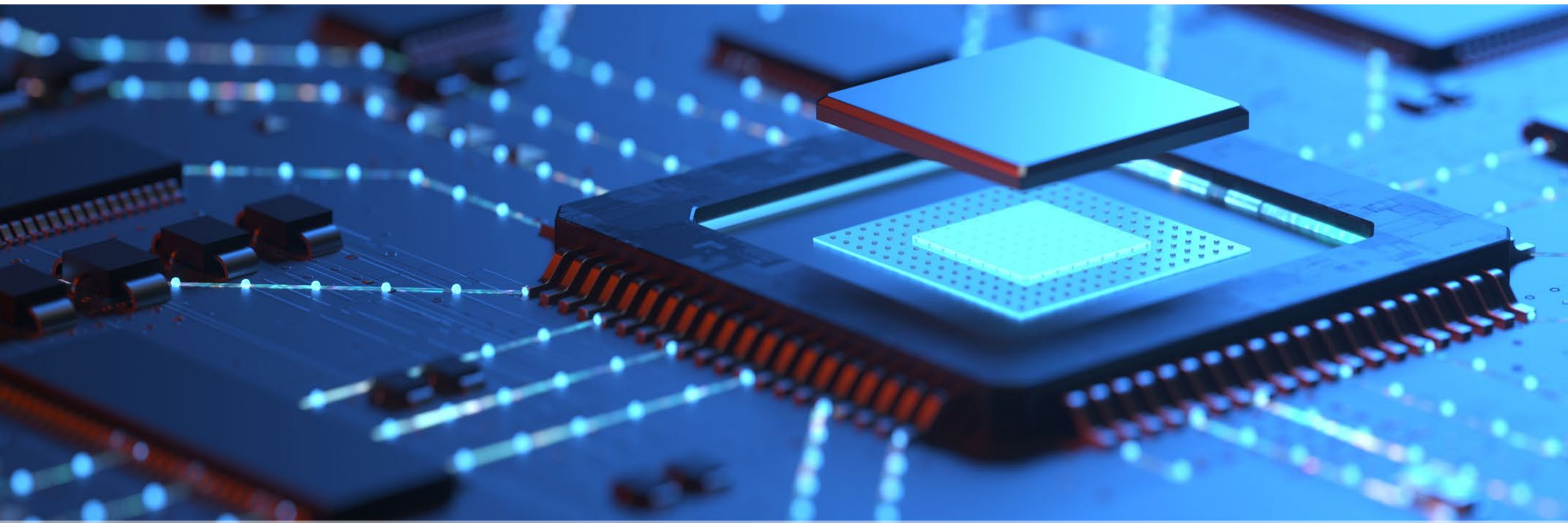
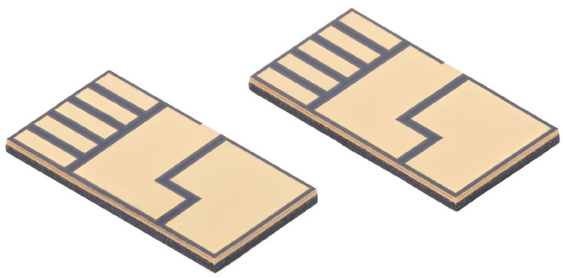


Diamond heat spreaders cool hot spots in silicon chips

Diamond has the highest thermal conductivity of any solid material, making it the perfect heat spreader for high power density semiconductor chips. In this case study we demonstrate diamond's ability to dramatically reduce hot spots in silicon chips, paving the way for faster, more reliable computational processing for high performance computing and artificial intelligence applications.



E6 metallized diamond heat spreaders

The opportunity

Solving complex problems at unprecedented speeds across multiple industries

High performance computing (HPC) is accelerating breakthrough developments across a range of fields, such as healthcare, financial services, defence and energy. HPC is based on clusters of powerful, state-of-the-art silicon processors undertaking complex calculations on big data sets at extremely high speed, and often involving applications running artificial intelligence (AI) processes.

The challenge

Thermal performance limitations of standard semiconductor packaging materials

The drive for faster HPC and AI platforms requires high power computing chips in heterogeneous packages, presenting considerable challenges for thermal management. Addressing these challenges requires best-in-class thermal packaging materials, capable of eliminating die hot spots and of dissipating high heat fluxes.

The solution

CVD diamond heat spreaders

Synthetic diamond's outstanding thermal conductivity provides a consistent heat spreading capability, unmatched by any other material, leading to reduced die temperatures, uniform heat fluxes, and a significant improvement in thermal performance. Element Six's Diafilm™ heat spreaders, grown by chemical vapour deposition (CVD), are available in metallized and unmetallized formats. Our world-leading range of thermal grades possesses thermal conductivities that far exceed those of traditional heat spreader materials (Figure 1).

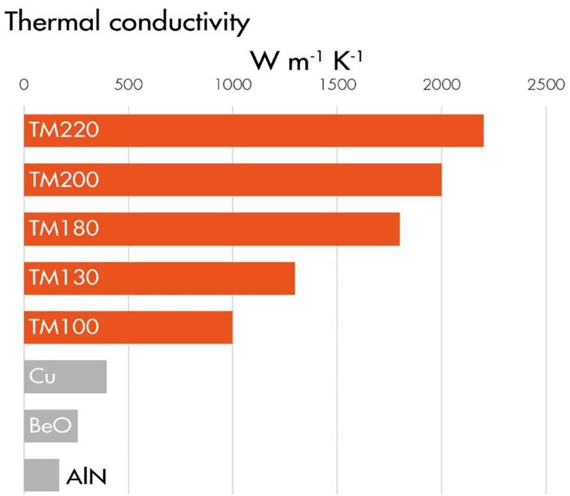


Figure 1 – Room temperature thermal conductivity of different thermal grades of synthetic diamond manufactured by Element Six, in comparison to standard thermal management materials.

When used with appropriate die attach methods, Diafilm™ heat spreaders provide reliable solutions for improved thermal performance of semiconductor chips. In collaboration with colleagues from A-Star's Institute of Microelectronics, we investigated the thermal performance improvement of diamond heat spreaders for a silicon thermal test chip, in combination with a hybrid microjet/microchannel cooler.

The results

Enhanced thermal performance in Si chips

We used a silicon thermal test chip, comprising 8 hotspot devices, each of size 450×300 μm^2, attached to a 400 μm thick Diafilm™ TM200 synthetic diamond heat spreader, which was in turn bonded to a hybrid microjet/microchannel cooler fabricated in silicon (Figure 2). Gold-tin solder was used at the primary and secondary thermal interfaces, and the thickness of the silicon test chip was 200 μm.

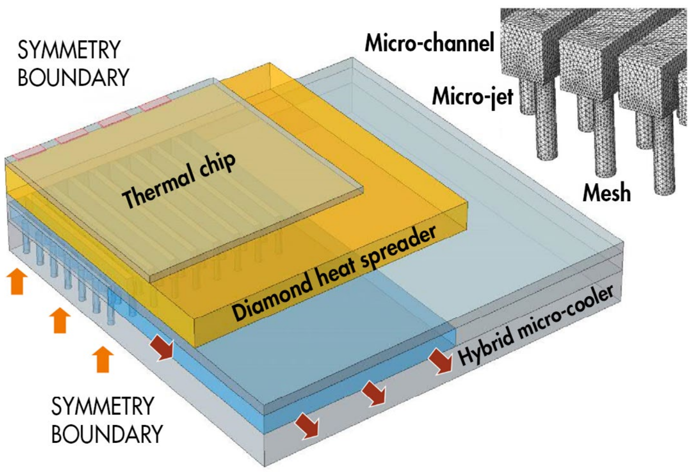


Figure 2 – Details of the die / heat spreader / micro-cooler stack used to investigate synthetic diamond's ability to cool hot spots in silicon chips.

The total power to the array of hotspots was increased up to a maximum of 100 W, equivalent to around 9.3 kWcm^{-2} power density per device.

The thermal performance of the package was evaluated by comparing plots of the maximum hotspot temperature versus total heating power, with and without a synthetic diamond heat spreader, as shown in Figure 3.

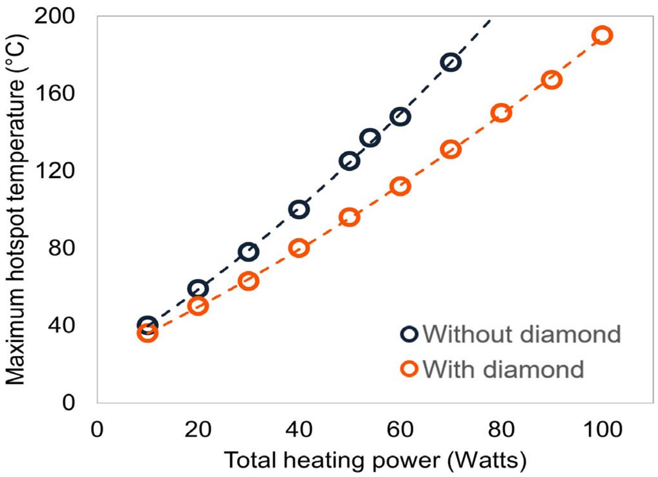


Figure 3 – Maximum hotspot temperature versus total heating power, with and without a diamond heat spreader.

As the total heating power is increased from 10 to 70 W, the reduction in maximum hotspot temperature enabled by synthetic diamond increases from 4 to 45 °C. In percentage terms, the temperature reduction increases from 10 to 26%, demonstrating how the benefits delivered by synthetic diamond heat spreaders increase as the dissipated power increases. In an AI or HPC application, this improvement in thermal performance translates into increased device performance and reliability.

Infra-red camera images taken at a heating power of 54 W show that the integration of synthetic diamond significantly reduces the overall maximum temperature from 140 to 102 °C (Figure 4).

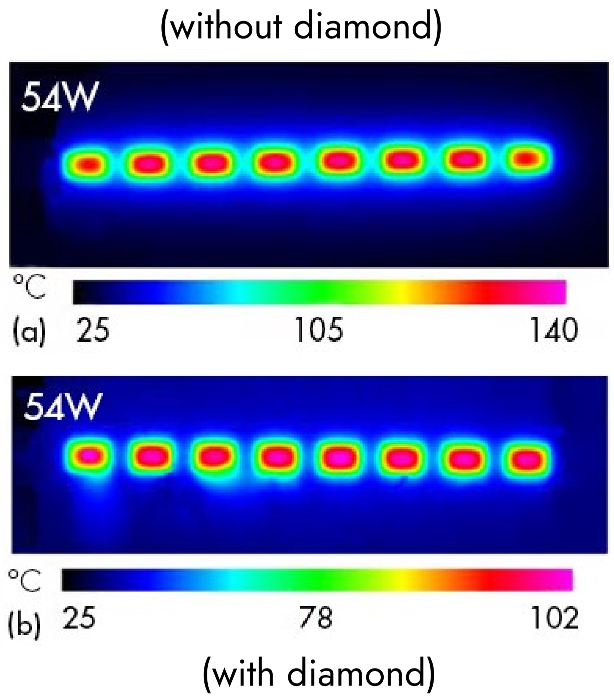


Figure 4 – Infra-red camera images at 54 W heating power (a) without and (b) with a diamond heat spreader.

Computer simulations of the heat flux at the upper surface of the microchannel/microjet cooler predict a significant improvement in the heat flux uniformity, illustrating the heat spreading effect of synthetic diamond (Figure 5).

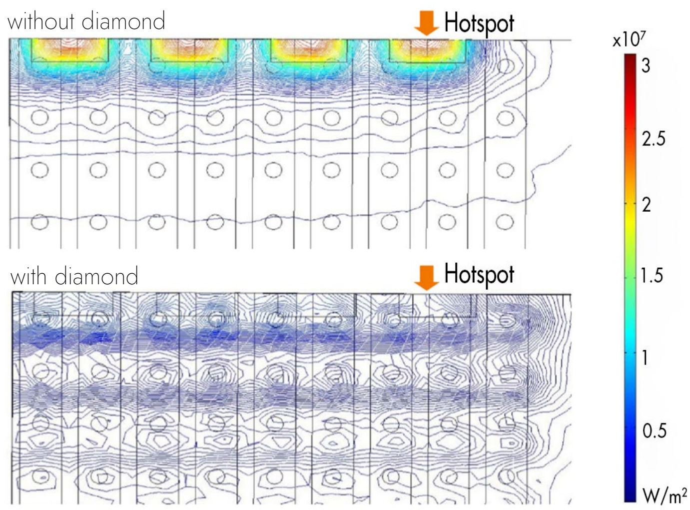


Figure 5 – Calculated heat flux at the upper surface of the microchannel/microjet cooler, with and without a synthetic diamond heat spreader.

A further improvement in thermal performance can be obtained by reducing the thickness of the silicon test chip from 200 to 100 µm: at a fixed maximum temperature of 180 °C, simulations indicate that the maximum total power can be increased from 100 W to 120 W. This shows that the benefit of a synthetic diamond heat spreader can be maximized by locating the synthetic diamond as close as practicable to the hot spot in the die.

These results show definitively that synthetic diamond heat spreaders can be successfully integrated with silicon chips to great effect, delivering the improved thermal performance and reliability required for high power density, high performance applications.

Advantages of Element Six CVD diamond

- Highest room temperature thermal conductivity of any material
- Electrically insulating
- High mechanical strength
- Very low weight
- Chemical inertness and low toxicity
- Broad range of diamond bonding solutions
- Range of thicknesses across large areas available
- Low roughness with high flatness possible

Figures 2, 4 and 5 are courtesy of A-Star's Institute of Microelectronics.

About Element Six

Element Six is a global leader in the design, development and production of synthetic diamond and tungsten carbide advanced material solutions. Part of the De Beers Group, our primary manufacturing sites are located in the UK, Ireland, Germany, South Africa, and the US.

Since 1946, our focus has been on developing the synthesis processes to enable innovative synthetic diamond and tungsten carbide solutions. As well as being the planet's hardest material, diamond's extreme and diverse properties give it high tensile strength, chemical inertness, broad optical transmission and very high thermal conductivity.

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