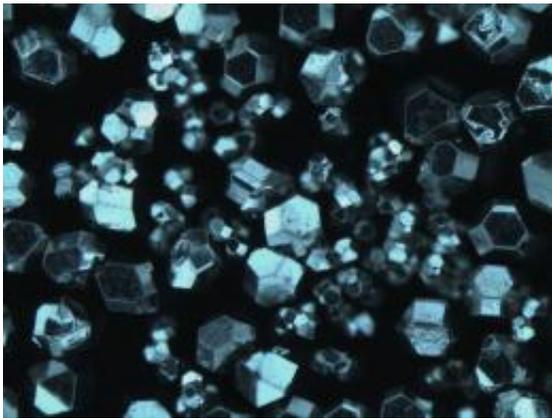


Silver-diamond composite offers cooling capabilities for electronics

March 1 2011, by Rick Robinson



A microscope image of diamond particles. (Credit: Jason Nadler)

(PhysOrg.com) -- Researchers at the Georgia Tech Research Institute (GTRI) are developing a solid composite material to help cool small, powerful microelectronics used in defense systems. The material, composed of silver and diamond, promises an exceptional degree of thermal conductivity compared to materials currently used for this application.

The research is focused on producing a silver-diamond thermal shim of unprecedented thinness – 250 microns or less. The ratio of silver to diamond in the material can be tailored to allow the shim to be bonded with low thermal-expansion stress to the high-power wide-bandgap semiconductors planned for next generation phased-array radars.

Thermal shims are needed to pull heat from these high-power semiconductors and transfer it to heat-dissipating devices such as fins, fans or heat pipes. Since the semiconductors work in very confined operating spaces, it is necessary that the shims be made from a material that packs high [thermal conductivity](#) into a tiny structure.

Diamonds provide the bulk of thermal conductivity, while silver suspends the diamond particles within the composite and contributes to high thermal conductivity that is 25 percent better than copper. To date, tests indicate that the silver-diamond composite performs extremely well in two key areas -- thermal conductivity and thermal expansion.

'We have already observed clear performance benefits -- an estimated temperature decrease from 285 degrees Celsius to 181 degrees Celsius -- using a material of 50 percent diamond in a 250-micron shim,' said Jason Nadler, a GTRI research engineer who is leading the project.

The researchers are approaching diamond percentages that can be as high as 85 percent, in a shim less than 250 microns in thickness. These increased percentages of diamond are yielding even better performance results in prototype testing.

Nadler added that this novel approach to silver-diamond composites holds definite technology-transfer promise. No material currently available offers this combination of performance and thinness.

Natural Thermal Conductors

Diamond is the most thermally conductive natural material, with a rating of approximately 2,000 watts per meter Kelvin, which is a measure of thermal efficiency. Silver, which is among the most thermally conductive metals, has a significantly lower rating -- 400 watts per meter K.

Nadler explained that adding silver is necessary to:

- bond the loose diamond particles into a stable matrix;
- allow precise cutting of the material to form components of exact sizes;
- match thermal expansion to that of the semiconductor device being cooled;
- create a more thermally effective interface between the diamonds.

Nadler and his team use diamond particles, resembling grains of sand, that can be molded into a planar form.

The problem is, a sand-like material doesn't hold together well. A matrix of silver -- soft, ductile and sticky -- is needed to keep the diamond particles together and achieve a robust [composite material](#).



This image shows different preparations of diamonds, ready for integration into a silver matrix. (Credit: Gary Meek)

In addition, because the malleable silver matrix completely surrounds the diamond particles, it supports cutting the composite to the precise dimensions needed to form components like thermal shims. And silver allows those components to bond readily to other surfaces, such as semiconductors.

Tailoring Thermal Expansion

As any material heats up, it expands at its own individual rate, a behavior known as its coefficient of thermal expansion (CTE).

When structures made from different materials -- such as a wide-bandgap semiconductor and a thermal shim -- are joined, it is vital that their thermal-expansion coefficients be identical. Bonded materials that expand at different rates separate readily.

Diamond has a very low coefficient of thermal expansion of about two parts per million/Kelvin (ppm/K). But the materials used to make wide-bandgap semiconductors -- such as silicon carbide or gallium nitride -- have higher CTEs, generally in the range of three to five ppm/K.

By adding in just the right percentage of silver, which has a CTE of about 20 ppm/K, the GTRI team can tailor the silver-diamond composite to expand at the same rate as the semiconductor material. By matching thermal-expansion rates during heating and cooling, the researchers have enabled the two materials to maintain a strong bond.

Unlike metals, which conduct heat by moving electrons, diamond conducts heat by means of phonons, which are vibrational wave packets that travel through crystalline and other materials. Introducing silver between the diamond-particle interfaces helps phonons move from particle to particle and supports thermal efficiency.

"It's a challenge to use diamond particles to fill space in a plane with high efficiency and stability," Nadler said. "In recent years we've built image-analysis and other tools that let us perform structural morphological analyses on the material we've created. That data helps us understand what's actually happening within the composite -- including how the diamond-particle sizes are distributed and how the [silver](#) actually surrounds the [diamonds](#)."

A remaining hurdle involves the need to move beyond performance testing to an in-depth analysis of the silver-diamond material's functionality. Nadler's aim is to explain the thermal conductivity of the composite from a fundamental materials standpoint, rather than relying solely on performance results.

The extremely small size of the thermal shims makes such in-depth testing difficult, because existing testing methods require larger amounts of material. However, Nadler and his team are evaluating several testbed technologies that hold promise for detailed thermal-conductivity analysis.

Provided by Georgia Institute of Technology

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