Sandia National Laboratories' unique approach to materials allows temperature-stable circuits

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ALBUQUERQUE, N.M — Sandia National Laboratories researcher Steve Dai jokes that his approach to creating materials whose properties won't degenerate during temperature swings is a lot like cooking — mixing ingredients and fusing them together in an oven.

Sandia has developed a unique materials approach to multilayered, ceramic-based, 3-D microelectronics circuits, such as those used in cell phones. The approach compensates for how changes due to temperature fluctuations affect something called the temperature coefficient of resonant frequency, a critical property of materials used in radio and microwave frequency applications. Sandia filed a patent for its new approach last fall. The work was the subject of a recently completed two-year Early Career Laboratory Directed Research and Development (LDRD) project that focused on understanding why certain materials behave as they do. That knowledge could help manufacturers design and build better products.

"At this point we're just trying to demonstrate that the technology is practical," Dai said. "Can we design a device with it, can we design it over and over again, and can we design this reliably?"

The familiar cell phone illustrates how the development might be used. The Federal Communications Commission allocates bandwidth to various uses — aviation, the military, cell phones, and so on. Each must operate within an assigned bandwidth with finite signal-carrying capacity. But as temperatures vary, the properties of the materials inside the phone change, and that causes a shift in the resonant frequency at which a signal is sent or received.

Because of that shift, cell phones are designed to operate squarely in the middle of the bandwidth so as not to break the law by drifting outside their assigned frequency range. That necessary caution wastes potential bandwidth and sacrifices higher rates at which data could move.

Dai worked on low-temperature co-fired ceramic (LTCC), a multilayer 3-D packaging and interconnection technology that can integrate passive components — resistors, capacitors and inductors.

Most mainstream LTCC dielectrics now on the market have a temperature coefficient of resonant frequency in a range as wide as that between northern Alaska in the winter and southern Arizona in the summer. Dai's research achieved a near-zero temperature coefficient by incorporating compensating materials into the LTCC — basically a dielectric that works against the host dielectric and in essence balances the temperature coefficient of resonant frequency. A dielectric is a material, such as glass, that does not conduct electricity but can sustain an electric field.

A graph shows the differences. Resonant frequencies used in various LTCC base dielectrics today appear as slanted lines on the graph as temperatures change. Dai's approach to an LTCC leaves the line essentially flat — indicating radio and microwave resonator frequency functions that remain stable as temperatures change.

He presented the results of the approach in a paper published in January in the *Journal of Microelectronics and Electronic Packaging*.

"We can actually make adjustments in the materials property to make sure my resonance frequency doesn't drift," Dai said. "If this key property of your material doesn't drift with the temperature, you can fully utilize whatever the bandwidth is."

Another advantage: Manufacturers could cut costs by eliminating additional mechanical and electrical circuits now built into a device to compensate for temperature variations.

One challenge was choosing different materials that don't fall apart when co-fired together, Dai said. Glass ceramic materials used in cell phone applications are both fragile and rigid, but they're also very solid with minimal porosity. Researchers experimented with different materials, changing a parameter, adjusting the composition, and seeing which ones worked best together.

He had to consider both physical and chemical compatibility. Physical compatibility means that as materials shrink when they're fired, they shrink in the same way so they don't warp or buckle. Chemical compatibility means each material retains its unique properties rather than diffusing into the whole.

The LDRD project created a new set of materials to solve the problem of resonant frequency drift but also developed a better understanding of why and how the processes involved in identifying the best materials work. "Why select material A and not B, what's the rationale? Once you have A in place, what's the behavior when you make a formulation change, a composition change, do little things?" Dai said.

Researchers looked at variables to boost performance. For example, the functional material within the composite carries the electrical signal, and researchers experimented with placing that material in different areas within the composite until they came up with what arrangement worked best and understood why.

The team also constructed a computational model to analyze what happens when materials with different properties are placed together, and what happens when they change their order in the stacked layers or the dimensions of one material versus another.

"We study all these different facets, the placement of materials, the thickness, to try to hit the sweet spot of the commercial process," Dai said.

Manufacturing can be done as simple screen printing, a low-cost, standard commercial process much like printing an image on a T-shirt. Dai said the idea was to avoid special requirements that would make the process more expensive or difficult.

"That's kind of the approach you try to take: Make it simple to use with solid understanding of the fundamentals of materials science," he said.

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