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Silicon and compounds get intimate

By Michael Hatcher

With an Intel executive blogging about integrated III-V and CMOS functionality, and DARPA setting up a three-pronged attack on the same topic, it's time for compounds and silicon to get up close and personal. Michael Hatcher reports.

"Compound semiconductors have always had a huge big brother over their shoulder, and it's very hard to compete with such a behemoth." That's Mark Rosker from the US Defense Advanced Research Projects Agency (DARPA), telling us what we already know about silicon semiconductors. But the good news for compounds is that there are now some major efforts going on to address this problem and to make silicon and III-V materials happy bedfellows.

Integration Game

Integration game: Under its new COSMOS program, DARPA has funded three projects, each with a different approach to integrating InP functionality with silicon CMOS processing for applications in digital–analog converters. Intel, Amberwave Systems and IBM are working on similar projects. Credit: IBM.

It's not a new idea, of course. What is new is DARPA's generous backing of three independent approaches to combining the benefits of the two technologies within the same device platform, each of which could receive around $18 million.

Rosker again: "If you have this technology in hand, you have the capability of building products, devices and circuits that will be absolutely revolutionary. There are an enormous number of circuits that would benefit from compound semiconductors, where today it's just cost-prohibitive to imagine doing that."

DARPA's three teams – led respectively by the familiar corporate faces of HRL, Raytheon and Northrop Grumman Space Technology – are by no means alone in imagining the possibilities that this convergence could bring. IBM is actively working on it, while Intel's executives have even taken to blogging on their company website about it. Mike Mayberry, director of component research at Intel, talked up the company's recent development of InGaAs-on-silicon transistors with epiwafer specialists at IQE.

Okay, but would Intel really consider using GaAs processes? Even while espousing the technological benefits offered by convergence in his blog, Mayberry trotted out the old "technology of the future – and always will be" joke that III-V companies have had to put up with for decades.

So maybe it makes more sense to look at what DARPA is intending to make happen in its new program, which the agency has denoted COSMOS, as in "Compound Semiconductor Materials On Silicon".

Back to Rosker: "The goal is basically to make a circuit so that it is absolutely seamless to the designer – whether they're using a silicon transistor or whether they're using GaAs. What you would ideally like is to be able to take whatever compound semiconductor you want and have that live inside the silicon circuit."

There's more than one way to do that. One is to take a CMOS-processed wafer, plus some micron-scale chips made using a III-V process – Rosker calls them chiplets – and to figure out a way to connect the two. This focus on assembly and interconnects is the approach that NGST is taking.

The extreme opposite of that scheme, explains Rosker, is to take a purely monolithic approach and integrate compounds without significantly changing the CMOS process – this is what the team headed up by Raytheon will be tackling. "That's tough," admits the program manager.

The reason that it's technologically tough is, of course, the lattice mismatch between silicon and III-V materials – the perennial stumbling block. While Raytheon will have its work cut out trying to achieve this monolithic approach, a separate collaboration outside the DARPA effort is also looking at how to solve the materials problem.

Though nowhere near the grand scale of the COSMOS program, Amberwave Systems has backing from the National Science Foundation and will work with principal investigators from Rochester Institute of Technology's microelectronics department.

Caught in a trap

So far, Amberwave's research team has been able to trap crystal defects arising from the lattice mismatch of germanium and III-Vs grown on silicon to within the first few hundred nanometers of the layers formed by epitaxial growth.

Because these defects are also confined laterally, to the sidewalls of narrow openings in a dielectric mask on a silicon wafer, it is possible to fabricate device structures on the defect-free stripes that remain, with Amberwave targeting resonant tunneling diodes for static RAM applications initially.

In the DARPA program, the agency has funded what you might call, in political speak, a third way. This team, led by HRL, will fully process a wafer using CMOS and partially process the compound semiconductor separately. The two wafers can then be bonded to each other.

Interestingly, although the agency did not specify any particular compound material in its COSMOS solicitation, all three teams have decided to focus on the same compound – InP.

So, what exactly are the COSMOS program members expected to deliver in terms of device technologies? Rosker reveals that the key application will be mixed-signal electronics – in particular, differential amplifiers, analog-to-digital converters (ADCs) and their digital-to-analog equivalents (DACs). "Building a high-performance ADC is really a classic problem in electronics," Rosker said.

The first phase of COSMOS will focus on differential amplifiers, circuits requiring only five transistors, two of which will be fabricated in InP. A key building block for the rest of the program, these amplifiers will then be used to develop more complex DACs. "In phase three, then we really do the impossible – we try to make an ADC," is how Rosker put it. Except that it won't be just any old ADC: "We'll make the world's best ADCs."

The technological specifications for those high-end ADCs are tough, to say the least. Ultimately, Rosker is asking for a 16-bit converter working at a bandwidth of 500 MHz and a power dissipation of less than 4 W.

Outside DARPA's demanding requirements for military deployments, Rosker believes that the initial applications will soon spill over into wide-scale commercialization, such as digital radio. This looks likely to be the first key application in the commercial world, although Rosker sees others. "Mixed signal is very important, but its applicability to other problems is going to be huge," he said. "In optoelectronics, what if I had the ability to embed lasers inside my silicon circuit? In optoelectronics, digital electronics, an entire gamut [of applications] are going to benefit from the technologies that we're going to develop."

Then, rather than competing with the silicon behemoth, compounds could sit happily with silicon CMOS and drive it to new heights. "Instead of competing, you could make a niche – to live inside, almost literally, the silicon world…I think that it's an opportunity for companies involved in compound semiconductors," concluded Rosker. "It's going to be a gold mine for them."

About the author
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