Extreme materials and ubiquitous electronics

December 3 2014, by Alice Mccarthy

Tomás Palacios

Nearly everyone seems to carry a cell phone or tablet. But if Tomás Palacios' vision of the future of electronics comes to bear, it will be increasingly difficult to separate electronics from all the other structures and materials surrounding us. An electrical engineer by training, Palacios, an associate professor of electrical engineering and computer science at MIT, develops new materials to bring electronic devices to the next level and beyond. "We are always trying to mix materials, engineering, and physics to create a prototype device that can get people excited about new applications and opportunities," he says.

Palacios believes we are at the most exciting time for semiconductor research in the last 30 to 40 years because of the advent of new materials with new unique properties. "My group works exactly at that intersection," he says. Currently, Palacios is intent on developing new applications based on two main types of semiconductor material families that he believes will shape the future of electronics: gallium nitride (GaN) and two-dimensional materials, such as graphene and molybdenum disulfide.

Gallium nitride reduces wasted energy

Roughly 60 years ago, silicon-based devices began to answer the challenge of that time, which was how to build larger and larger computers. "Today's challenge is energy," says Palacios, "and we believe that gallium nitride can be just as important in addressing the energy challenge as silicon was in addressing the information challenge."

With energy demands expected to double within the next 20 to 25 years, the associated technical, political, and societal challenges are obvious. But Palacios finds some "good" news in our current state of energy use. "Half of the electricity we make now is wasted as heat and never used to produce actual work," he explains. "Gallium nitride gives an opportunity to reduce a big portion of that wasted 50 percent." GaN-based lighting, for example, is expected to save between 10 to 20 percent of the world's electricity, while high-voltage GaN switches used inside power supplies could cut the energy wasted by another 10 to 20 percent.

As a principal investigator in the MIT Microsystems Technology Laboratories (MIT/MTL), Palacios directs the MIT/MTL Gallium Nitride Energy Initiative. Its goal is to facilitate the research of about 15 MIT groups with industry to advance the science and engineering of

GaN-based materials and devices for energy applications. If Palacios and colleagues are successful, he estimates that GaN could save $1 trillion in energy costs within 10 to 15 years. But first, an ecosystem of industries working with GaN needs to be established including developing the basic materials, the circuits, the devices, and ultimately the systems that will end up producing that $1 trillion of energy savings by 2025.

2-D semiconductor "extreme" materials

Two-dimensional (2-D) materials, like graphene and molybdenum disulfide, are truly unique. "They are the thinnest materials you can think of," says Palacios. Just one-to-three atoms thick, these layered materials are orders of magnitude stronger than steel and much lighter. "They are truly extreme materials," he adds. "There is nothing lighter, more flexible, more transparent, nothing better for ubiquitous electronic devices."

Palacios' research group is trying to find ways of increasing the market for electronics by 10-fold. "What we do with 2-D semiconductors is to bring electronics to the 95 percent of objects that surround us but do not have electronics yet," he explains of his vision of ubiquitous electronics. "If we are able to do that, we can increase the impact and reach of the electronics industry at least by 10-fold." As director of the MIT/MTL Center for Graphene Devices and 2D Systems, Palacios and colleagues from 15 to 20 research groups at MIT partner with more than 10 companies from around the world to advance the development and application of graphene and other 2-D semiconductors and materials.

"If we are to embed some level of intelligence in every object that would change electronics and it would change society," Palacios says. Using 2-D materials, his research group has already developed integrated electronic circuits into paper, fabric, and textiles. He is even using a 3-D printer to fabricate objects with integrated sensors and energy harvesting devices. Palacios' view of the reach of embedded electronics is itself extreme, ranging from embedded window displays to a wide variety of biomedical electronics.

Commitment to industrial collaborations

"Everyone at MIT understands that to change the world, the basic research done in our labs can't stay in our labs," says Palacios. To make that a reality for his research, Palacios teams with many industrial partners and organizations on many different levels.

At any given time, between three and five visiting industrial engineers will be in residence at his lab for periods ranging from just a few weeks to a couple of years. His students often work in the facilities of his industrial partners as well. Regardless of how the relationship is structured, Palacios believes the best collaborations are those where the industrial collaborator is "all-in"—heavily enthused, engaged, and committed to the project.

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Provided by Massachusetts Institute of Technology