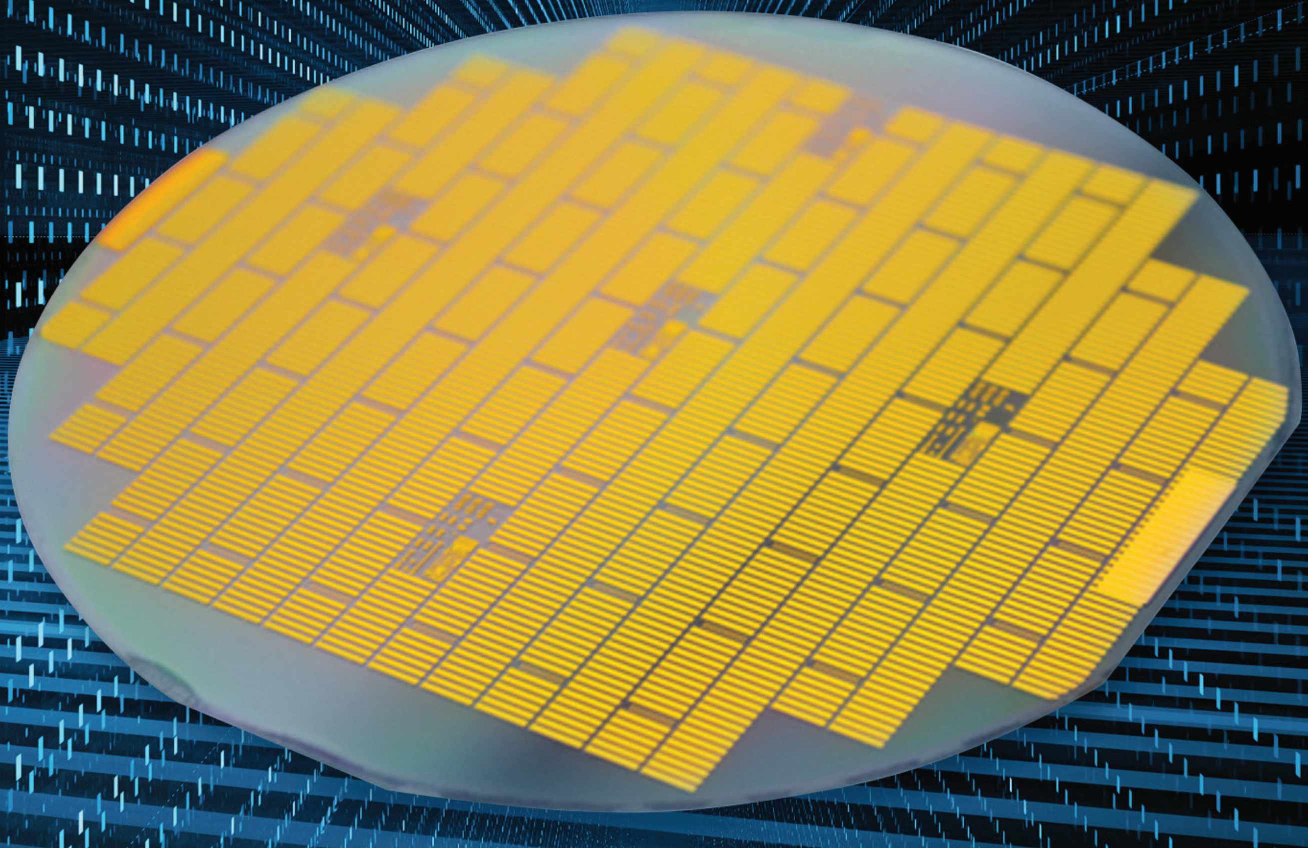
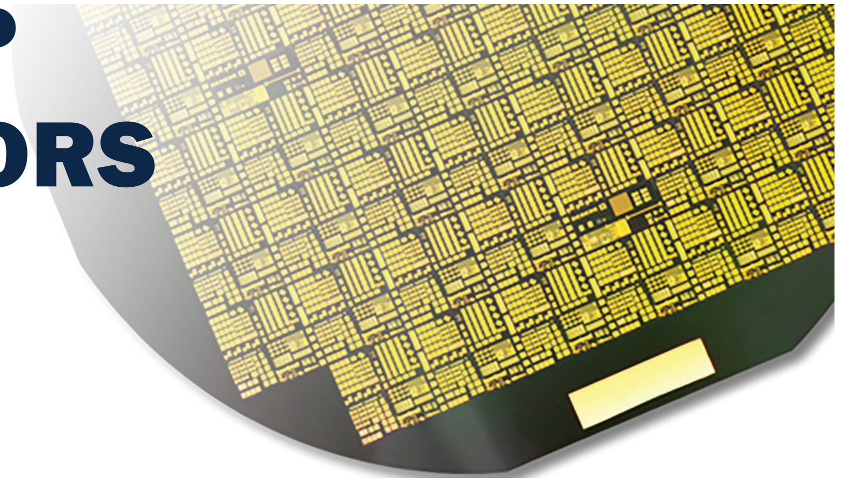
DARPA

WIDE BANDGAP SEMICONDUCTORS



Advancing National Security Through Fundamental Research

WIDE BANDGAP SEMICONDUCTORS



THE NEED AND OPPORTUNITY

Our military systems depend critically on the microsystems contained inside. For decades, DARPA has invested in research to make these technologies more capable. That has helped engineers deliver an ever expanding array of compact devices and portable platforms to support defense training and operations. As military capabilities have evolved, so too have the demands placed on these microelectronics – from operating at higher frequencies to integrating billions of transistors on a single chip.

For the past two decades, and particularly the past two years with the Electronic Resurgence Initiative, DARPA has invested heavily in electronics R&D to uncover novel materials and designs capable of eking out more performance and functionality. Silicon has long been the standard semiconductor material for microelectronics and still is for a large number of commercial and defense applications. However, the theoretical limits on how much more performance silicon can deliver – particularly for systems operating at higher power and frequencies – are being reached in practice. That reality check, long in the making, has driven a search for alternative semiconductor technologies.

In the 1990s, DARPA's exploration of novel architectures and alternative semiconductor materials accelerated development of compound semiconductor technologies that unlike silicon are based on crystals made of more than one element. One payoff was the maturation of gallium arsenide (GaAs) with efforts including like the Microwave and Millimeter Integrated Circuit (MIMIC) program and the Microwave and Analog Front End Technology (MAFET) program. The properties of GaAs allows transistors made with it to operate well beyond the performance limits of silicon, enabling radar and radios to operate at higher frequencies and bandwidths without performance degradation. These investments in fundamental and applied semiconductor science also provided the defense community with access to affordable components. On the commercial side, the same support fueled the society-transforming cellular phone revolution in the 1990s.

The success of GaAs technology demonstrated the defense relevance and commercial viability of semiconductor technology beyond silicon and made a once-exotic research material into a commodity technology. Even as GaAs was maturing into an industry, however, researchers sponsored by the Office of Naval Research (ONR) and academic institutions in the 1980s already had begun to identify the next leap in semiconductor materials. Wide bandgap semiconductor (WBGS) materials – in which the energy difference (bandgap) for electrons close to atoms and electrons that can conduct through the semiconductor is larger than the bandgap of conventional materials like silicon – appeared promising due to their ability to move electrons rapidly, but also handle large electric fields. This combination of high current capability and high voltage drives the ability of these materials to deliver more radiofrequency (RF) power – a critical capability for defense technologies including advanced radar and electronic warfare systems.

Although several candidate WBGS materials were in development around the world, gallium nitride (GaN) and its alloys appeared the most promising. GaN has an even wider bandgap than GaAs, which means it can operate at voltages that would ruin devices made out of GaAs, enabling the design of microsystems that can operate at higher powers. Fundamental research funded by ONR throughout the 1980s and 1990s identified GaN as the premier wide bandgap material to develop and laid the groundwork for the crystal growth procedures, baseline device structures, and other supporting industrial components that could move the idea of GaN transistors from a theoretical construct to a viable technology.

THE DARPA SOLUTION

Were it not for these fundamental research efforts, DARPA would not have been able to justify major follow-on investments to rapidly advance GaN technology. In 2001, DARPA established the Wide Bandgap Semiconductors for RF Applications (WBGS-RF) program. WBGS-RF sought to leverage the proven promise of GaN into an industrially relevant technology that could further the cause of national defense. When the program started, GaN could only be delivered on small semiconductor wafers riddled with so many flaws, called micropipes, that metaphors based on Swiss cheese come to mind. From that inauspicious start, the WBGS-RF program systematically addressed materials challenges before progressively taking on the device and circuit-design challenges. This persistent investment of resource and talent led to practical GaN materials specifically for use within Microwave Monolithic Integrated Circuit (MMIC) technologies, which are critical for military RF-systems like radar and radio.

The WBGS-RF program's research relied heavily on industry-academic collaboration. Raytheon, TriQuint (now Qorvo), and Northrop Grumman served as primary performers, collaborating with academic teams that continued to advance the fundamental research. The defense performers helped tailor the resulting technology for military use and ensured production could scale for DoD needs. Academic teams from MIT; Rensselaer Polytechnic Institute; University of South Carolina; University of California, Los Angeles; University of Florida; and North Carolina State University conducted research that was critical to understanding and developing physical models and device and system operation, uncovering and modeling mechanisms of failure, and optimizing GaN as a new and maturing material driving the evolution of microsystems.

Contributing to the collaboration among academic and commercial performers in the WBGS-RF program was a tri-service team, which included the Naval Research Laboratory (NRL), Air Force Research Laboratory (AFRL), and Army Research Laboratory (ARL). The Services team conducted tests and evaluated performer devices throughout the program, providing early assessment of device reliability, government insight regarding future investment, and early transition partner interaction.

In parallel with the WBGS-RF program, ONR funded several university-level efforts such as the Center for Advanced Nitride Electronics (CANE) and other Multidisciplinary University Research Initiative (MURI) projects to improve the understanding of the fundamental physical mechanisms underlying certain limitations in GaN-based transistors and circuits. This work directly affected the technology's rapid progression within WBGS-RF and paved the way for additional GaN programs, including the DARPA Nitride Electronic NeXt-Generation Technology (NEXT) program.

THE IMPACT

The WBGS-RF program ushered GaN from a glimmer-in-the-eye status into a broad DoD capability with far-ranging commercial and academic implications. The broad impact of GaN electronics is hard to overstate. GaN allows the DoD to have electronics that can handle high-power RF signals that would physically destroy equivalent circuits made of other materials. This capability lies at the heart of radars, jammers, and other electronic warfare components that today provide advantages over adversaries' RF technology.

LOOKING AHEAD

As a result of the WBGS-RF program, these new GaN capabilities were adopted for the Navy's premier surface radar, the Air and Missile Defense Radar (AMDR), a priority technology transition from the outset of the program. The electronic warfare community also became an early adopter, transitioning GaN to the Next Generation Jammer (NGJ) program, which is the Navy's fundamental airborne jamming capability.

GaN technology also drives the Space Fence array, which provides unprecedented space situational awareness, and the Navy's Surface Electronic Warfare Improvement Program (SEWIP). And beyond defense, GaN has become part of the technology portfolios of all major RF semiconductor players today.

Gallium nitride is central to many U.S. military assets including AN/TPY-2 radar systems (left) and the Navy's Air and Missile Defense Radar.

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