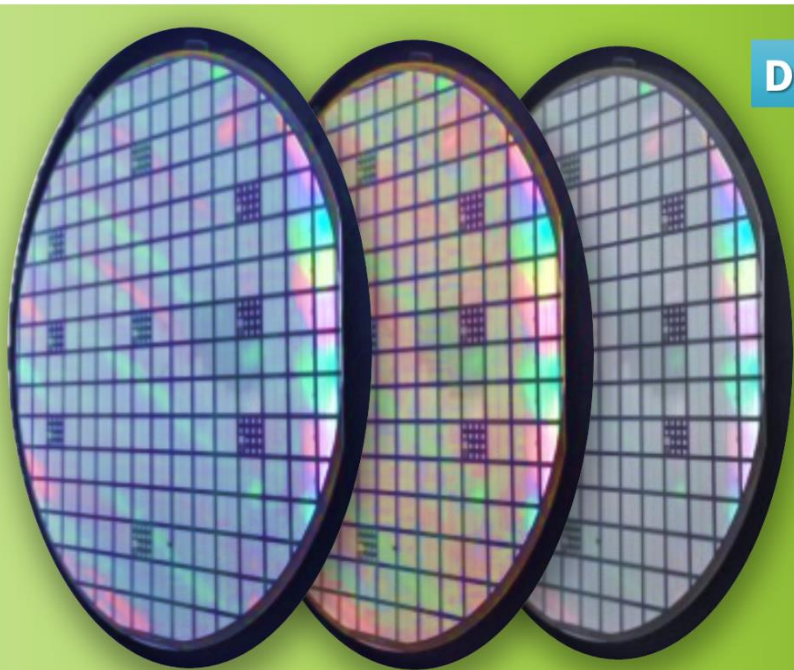
DOE SBIR/STTR Success



100 mm – diameter silicon carbide wafers on which 6.5 kV junction field effect transistors (JFETs) have been fabricated through deposition of n-doped epitaxial layers, plasma etching, implantation, and subsequent metallization.

UNITED SILICON CARBIDE, INC.

United Silicon Carbide, Inc. (UnitedSiC) is a leader in the development of the next generation diodes and transistors making up the building blocks of power conversion circuits, which are designed to convert electricity between different currents, voltage levels, and frequencies. Power conversion is a vital function in today's increasingly electrified world and an indispensable one for integrating intermittent energy sources such as wind and solar into the existing electric grid infrastructure. Power semiconductor devices play a major role in many other fields, including aerospace, telecommunications, and automotive systems, particularly in hybrid, electric, and fuel cell vehicles.

FACTS

PHASE III SUCCESS
UnitedSiC has obtained a return of multiple times the DOE SBIR investment. UnitedSiC's commercial business has tripled in 2017 with the projection of tripling again at the end of 2018.

IMPACT
UnitedSiC has developed a high-yield, SiC-based JFET, which operates at higher current and voltage ratings than comparable devices, allowing for increased conversion efficiency, and lighter and less expensive power converters.

DOE PROGRAM/OFFICE
Energy Storage Research Program, Office of Electricity and Energy Reliability (OE).

HTTP://UNITEDSIC.COM/

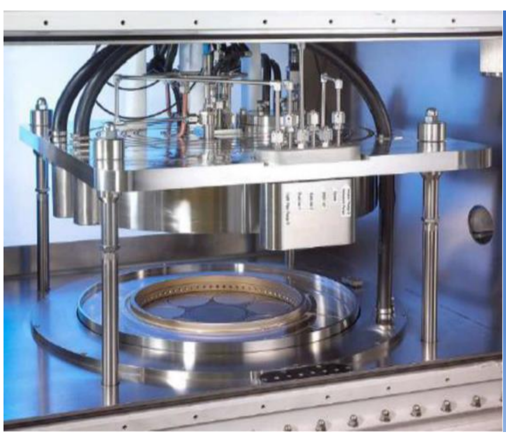
The challenges of modern power electronics applications have recently contributed to the development of silicon carbide (SiC) semiconductor material as a replacement for conventional silicon (Si) due to its larger bandgap and higher electron mobility, which allows SiC-based diodes and transistors to operate at higher voltages, temperatures, and frequencies, and with lower losses. Presently, UnitedSiC manufactures SiC diodes and transistors used in everything from switch-mode power supplies to on-board chargers for electric vehicles, to solar inverters, and industrial motor drives.

The creation of UnitedSiC can itself be considered an SBIR success story. The Company was founded in 1999 by a team of graduate students from Rutgers University. Much of the early funding of the company came through the SBIR / STTR system from an assortment of agencies. In 2009, Chris Dries took over the role of President and CEO of the company, purchasing the assets of the business with his former colleagues from a previously successful venture named Sensors Unlimited. In fact, Sensors Unlimited was also born out of the SBIR system beginning in 1991. It became extremely successful, ultimately selling for over $600M to a larger corporation. Dr. Dries wanted to invest a portion of those proceeds in a project in which he was directly involved, and saw an opportunity in UnitedSiC where the team had been utilizing SBIR funds without significant commercialization outcomes. The decision came from an experience-driven understanding that it takes about 20 years for devices based on a new material or class of materials to become commercially viable. "Given that the first SiC-based schottky diodes were produced in 2000 by a couple of early companies," Dr. Dries explains, "2009 [the year UnitedSiC was acquired] seemed like a great time to invest in SiC devices." Currently, UnitedSiC has accrued a return of multiple times the DOE SBIR investment. Sales of its devices have climbed recently, and UnitedSiC's commercial business has tripled in 2017 with the projection of tripling again at the end of 2018. However, market entry took much longer than Dr. Dries had expected due to technical challenges involved with transferring the numerous devices' fabrication processes on 4- and 6-inch diameter SiC wafers to commercial foundries.

UnitedSiC's core technology is a high-yield, SiC-based junction field effect transistor (JFET). Thanks to extensive R&D, UnitedSiC has developed a unique JFET design that allows the device to operate at higher current and voltage ratings as compared to comparable devices available on the market. The innovative design involves a vertical trench technology as opposed to the more commonly used planar technology, resulting in a higher operating current per unit area and generates two times the number of devices on each SiC substrate compared to the competition. UnitedSiC's design, which involves the fabrication of channels running vertically from the top of device down into the substrate was originally conceived at Rutgers' University and exclusively licensed by UnitedSiC. However, the initial resulting yield was low and the device's performance was significantly raised only after talented scientists from the Si industry in Silicon Valley were hired to tackle the underlying materials science issues, which had a similarity with those already known in the fabrication of Si-based devices.

The increasing demand for switching devices operating at larger voltages and frequencies than currently available is based on the consideration that these devices will have increased conversion efficiency and can greatly shrink the weight and cost of power converters by reducing cable size, transformer size, and eliminating forced convection cooling systems. UnitedSiC undertook the challenging development of a high voltage transistor during a Phase II DOE SBIR project funded by the Energy Storage Research Program managed by Dr. Imre Gyuk within the Office of Electricity and Energy Reliability (OE), and carried out in collaboration with Dr. Stan Atcitty at Sandia National Laboratories. During this project, which ended in 2015, Dr Dries' team successfully demonstrated SiC power switch modules operating at 6.5 kV, which involved the deposition of a nearly 60µm-thick epitaxial SiC layer on the SiC substrate, roughly 10 times thicker than usually done in order to sustain the increased voltage. Film thicknesses in this range are extremely difficult to achieve because film growth is a non-equilibrium, kinetic process in which the crystalline quality of the material deposited tends to deteriorate as thickness increases due to the introduction of lattice defects. Although the UnitedSiC's team was successful in demonstrating the 6.5 kV modules, the devices did not achieve market entry due to the added complexity for depositing such thick layers, which significantly increased costs. "Nevertheless," Dr. Dries recalls, "the OE SBIR project really informed our thinking on how to attack that voltage class of products in the future." Aware of the cost barrier, Dr. Dries' team did not try to pursue small improvements to the initial design but looked at other ways to solve the problem, finally developing a completely different design, which today makes up the Super Cascode series, one of the strongest product lines in the UnitedSiC's portfolio. The Cascode design entails the connection of lower voltage transistors in series in order to achieve the desired high voltage. UnitedSiC's commercial 1200 V transistors are used to build a composite module with the same functionality as a 6.5 kV transistor at much lower cost. "When you encounter a difficult problem, you start thinking of ways to solve it that are more likely to yield a commercial outcome", explains Dr. Dries.

After the OE SBIR, UnitedSiC received additional funds from DOE to develop the Super Cascode through the PowerAmerica initiative, which provides support for developing cost-competitive WBG technologies with a 50% company match. Currently, UnitedSiC has achieved numerous sales of individual Super Cascode components, mainly in Europe. Sales of other products have also risen recently, particularly sales of transistors for on-board charging in electric and plug-in hybrid electric vehicles. UnitedSiC's devices are shipping in volume in commercial cars with widespread adoption in China. Most recently, UnitedSiC's devices have been chosen for a large number of Fast Charging Stations for EVs here in the United States, and support many other power conversion applications in the US, Europe, and Japan. UnitedSiC's production is expected to scale up significantly in the coming years and the company has secured many years' worth of supply of SiC raw material through contractual agreement. Meanwhile, more resources are being invested within the U.S. to increase SiC bulk crystal production, the supply of which represents the main constraint to an increased device production in the near future.



Hot-wall CVD planetary reactor capable of 6 x 4" wafers used for 4H-SiC epitaxial deposition

When asked about the impact of an SBIR award, Dr. Dries replied that the SBIR program has been critical to UnitedSiC's growth because it served the function of an external venture capital (VC) without the loss of ownership associated with external offers. "The SBIR program has been a great partnership for us because it has allowed us to leverage our own personal investment into the company."

Written By Claudia Cantoni, Commercialization Program Manager, DOE SBIR/STTR, April 2018.