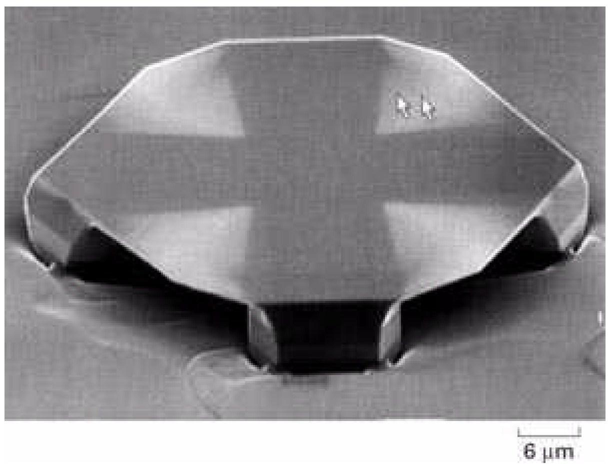
Improved Silicon Carbide Crystals Grown From Atomically Flat Surfaces

The NASA Glenn Research Center is demonstrating that atomically flat (i.e., step-free) silicon carbide (SiC) surfaces are ideal for realizing greatly improved wide bandgap semiconductor films with lower crystal defect densities. Further development of these improved films could eventually enable harsh-environment electronics beneficial to jet engine and other aerospace and automotive applications, as well as much more efficient and compact power distribution and control. The technique demonstrated could also improve blue-light lasers and light-emitting-diode displays.



A flattened and enlarged SiC mesa. The lighter, V-shaped sections (see arrows) are the webbed material that was grown between the legs of the darker, plus-sign-shaped original mesa.

Long description of figure 1 A flattened and enlarged silicon carbide mesa is shown. The image is a scanning electron microscope photograph that looks like a flat hexagonal-shaped tabletop (the part of the structure that was experimentally grown), residing on top of smaller plus-sign-shaped mesa support legs (the part of the structure that is the pregrowth mesa pattern etched into the wafer surface prior to growth). The hexagonal tabletop width and the plus-sign-shaped support mesa width are approximately 50 micrometers. The thickness of the hexagonal tabletop itself is about 1 micrometer, and the height of the plus-shaped support structure is about 8 micrometers above the floor of the structure formed by the etched wafer surface. The lighter, V-shaped sections are the webbed material that was grown between the legs of the darker, plus-sign-shaped original mesa.

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Step-free surfaces are produced on commercial on-axis 4H-SiC wafers by first dry etching trench patterns into the wafer surface to form an array of isolated growth mesas. Pure step-flow growth, which permits substrate polytype stacking to be maintained in the epilayer, is then used to grow all initial surface steps on top of each mesa over to the mesa edge, leaving behind an array of mesas with top surfaces entirely free of atomic steps. When a proper pregrowth mesa shape was chosen and new island nucleation was suppressed, thin cantilevered webs were grown that extended laterally from the top edges of step-free mesas. The preceding photomicrograph illustrates how thin lateral webbing produced an enlarged step-free hexagonal tabletop starting from a plus-shaped pregrowth mesa. Because the crystal structure of the webbing is established laterally from the top of the mesa sidewalls, successful overgrowth of crystal defects located in the substrate trenches below the webbing is accomplished.

The ideal step-free surfaces can then be used to carry out a step-free surface heteroepitaxy process that has produced the best-quality 3C-SiC films ever reported. Lowering the growth temperature after step-free surface formation induced island nucleation and growth of 3C-SiC on the step-free basal plane 4H-SiC surfaces. In this situation, the film crystal structure changed from a 4H structure to a 3C-SiC structure. In addition, we discovered that the initial 3C-SiC bilayers must be nucleated slowly to achieve 3C-SiC films free of stacking fault defects. The following figure compares 0.2- by 0.2-mm mesas, both topped with a nearly 2-µm-thick 3C-SiC film and thermally oxidized to reveal stacking fault defects, which were grown with a high initial island nucleation rate (left) and with a low initial island nucleation rate (right). The behavior observed in this figure is partly attributed to the difference in interatomic spacing between the 3C and 4H crystal structures of SiC. NASA scientists suggest that the single-island growth mode, whereby a single 3C island nucleates and expands laterally to cover the mesa before a second interfering 3C island nucleates, is required during the initial stages of growth to obtain high-quality 3C-SiC films. The experimental findings indicate that lattice mismatch was (at least partially) relieved without generating stacking faults that threaded to the surface of the film. Further growth and characterization experiments are being undertaken, including the fabrication of prototype 3C-SiC devices and attempting step-free surface heteroepitaxy of aluminum gallium nitride films on 4H- or 6H-SiC substrates.

3C-SiC films on flattened mesas after thermal oxidation that reveals crystal defects. The defect-free film shown on the right was made using step-free surface heteroepitaxy.

Long description of figure 2. 3C silicon carbide films are shown on flattened mesas after thermal oxidation that reveals crystal defects. A top-view microscopic photograph of two square mesas (each with dimensions of 0.2 by 0.2 millimeters) is shown in the figure. The mesa on the left exhibits numerous dark line and triangle outlines that indicate the presence of stacking fault defects. The mesa on the right is featureless, indicating that it is free of stacking fault defects. The defect-free film shown on the right was made using step-free surface heteroepitaxy.

Further information about the benefits of SiC electronics and research at Glenn is available online http://www.grc.nasa.gov/WWW/SiC/SiC.html.

PDF files of peer-reviewed scientific papers describing the work in detail also are available:
http://www.grc.nasa.gov/WWW/SiC/publications/ICSCRM2001Web.pdf
http://www.grc.nasa.gov/WWW/SiC/publications/ICSCRM2001-3Chepi.pdf

This technology is covered by U.S. Patents 6,461,994 B2 and 6,488,771 B1, which are available for licensing through the NASA Glenn Commercial Technology Office. **These patents can be accessed online at the U.S. Patent and Trademark Office. http://www.uspto.gov/**

Glenn contact: Dr. Philip G. Neudeck, 216-433-8902, Philip.G.Neudeck@nasa.gov
Ohio Aerospace Institute (OAI) contact: Andrew J. Trunek, 216-433-6736, Andrew.J.Trunek@nasa.gov
Sest, Inc., contact: ; and J. Anthony Powell, 216-433-3652, J.A.Powell@nasa.gov
Author: Dr. Philip G. Neudeck
Headquarters program office: OAT
Programs/Projects: CICT, ECT