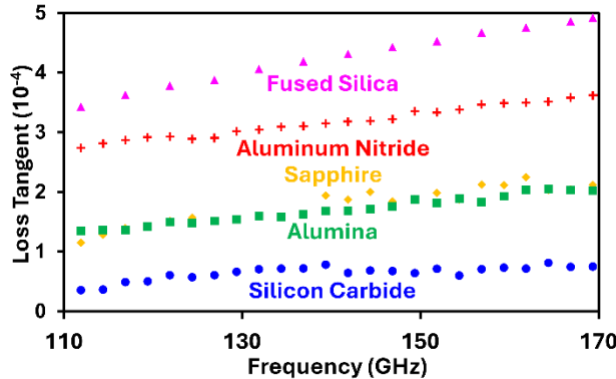


Ordinary and Extraordinary Permittivities of 4H SiC at Different Millimeter-Wave Frequencies and Temperatures

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Hexagonal semiconductors such as 4H SiC have important high-frequency, high-power, and high-temperature applications. The applications require accurate knowledge of both ordinary and extraordinary relative permittivities, $\epsilon_{\perp}$ and $\epsilon_{\parallel}$, perpendicular and parallel, respectively, to the c axis of these semiconductors. However, due to challenges for suitable test setups and precision high-frequency measurements, little reliable data exists for these semiconductors especially at millimeter-wave frequencies. This talk reports $\epsilon_{\perp}$ and $\epsilon_{\parallel}$ of high-purity semi-insulating 4H SiC

from 55 to 330 GHz, as well as their temperature dependence enabled by improving the measurement precision to two decimal points. For example, at room temperature, real $\epsilon_{\perp}$ and $\epsilon_{\parallel}$ are constant at 9.77 ± 0.01 and 10.20 ± 0.05 , respectively. By contrast, the ordinary loss tangent increases linearly with the frequency f in the form of $(4.9 \pm 0.1) \times 10^{-16} f$. The loss tangent, less than 1×10^{-4} over most millimeter-wave frequencies, is significantly lower than that of sapphire, our previous low-loss standard. Finally, both $\epsilon_{\perp}$ and $\epsilon_{\parallel}$ have weak temperature coefficients on the order of $10^{-4} / ^{\circ}\text{C}$. The knowledge reported here is especially critical to millimeter-wave applications of 4H SiC, not only for solid-state devices and circuits, but also as windows for high-power vacuum electronics.



James C. M. Hwang received the B.S. degree in physics from National Taiwan University, and the M.S. and Ph.D. degrees in materials science and engineering from Cornell University. He is currently a Professor at the Department of Materials Science and Engineering, Cornell University. Prior to that, he spent most of his academic career with Lehigh University, after years of industrial experience at IBM, Bell Labs, GE, and GAIN. He cofounded GAIN and QED; the latter became the public company IQE and remains the world's largest compound-semiconductor epitaxial wafer supplier. He was a Consultant for the U.S. Air Force Research Laboratory, and a Program Officer for GHz-THz Electronics with the Air Force Office of Scientific Research. He was an IEEE Distinguished Microwave Lecturer. He is an IEEE Life Fellow and an Editor of IEEE Journal of Microwaves. He has worked for decades on

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