March 06, 2014

Two-Dimensional Materials: Mechanical Stiffness, Strength and Reliability

Jeffrey W. Kysar

Professor

Department

of Mechanical Engineering

Columbia University

New York, NY 10027

Abstract: Two-dimensional materials are planar molecules of arbitrary extent that consist of one or possibly a few atomic layers. Graphene, the archetypal two-dimensional material, consists of a single close-packed array of carbon atoms. Another, molybdenum disulfide, consists of three atomic layers: a close-packed array of molybdenum atoms sandwiched between two close-packed arrays of sulfur atoms. Two-dimensional materials have many potential applications due to their unique electronic, optical and mechanical properties. The focus of this talk is on the mechanical properties of graphene and molybdenum disulfide. We will discuss methods to isolate two-dimensional materials via mechanical exfoliation and subsequently to make single crystal specimens via nanofabrication methods. An atomic force microscope or a nanoindenter is used to indent a freestanding circular film. The experimental results suggest the mechanically exfoliated single crystal materials to be free of defects. Thus, the breaking strengths of graphene and molybdenum disulfide represent their respective intrinsic strengths, or the maximum stress that a material theoretically can support. In fact the mechanical strength exhibited by graphene is in excess of 100 GPa, making it the strongest material ever characterized. We will also discuss a multiscale model of the stress-strain constitutive parameters of graphene and molybdenum disulfide based upon ab initio Density Functional Theory (DFT) calculations. The theory is implemented into the finite element method to validate the multiscale model against experiments. Finally we will discuss graphene grown by Chemical Vapor Deposition (CVD) using industrially scalable processes. The CVD grown graphene is polycrystalline, yet upon optimization of the CVD parameters, the strength of the polycrystalline graphene can achieve a very high fraction of the intrinsic strength of defect-free single crystal graphene.

Biography: Jeffrey W. Kysar is a Professor of Mechanical Engineering at Columbia University. He received his B.S. degree from Kansas State University and his Ph.D. from Harvard University. He has been a visiting professor at the École Nationale Supérieure des Mines de Paris. His current research interests are in the field of mechanical properties of small-scale materials from a combined experimental, computational and analytical perspective. Recent projects by his research group include: experimental characterization and theoretical development of the non-linear elastic properties of graphene and other monatomic thin film materials such as molybdenum disulfide; fabrication of crack-free blanket films of nanoporous gold onto silicon wafers for incorporation into micro-electro-mechanical systems (MEMS); fundamental study of the deformation mechanisms of monazite (lanthanum phosphate) which is a ceramic that deforms plastically; as well as the development of novel methods to characterize the spatial variation of material defects within metals that are deformed plastically. In 2012 he received the International Journal of Plasticity Young Researcher Award. In 2010 Science Watch recognized him and his coauthors for “the most-cited chemistry report published in the last two years, excluding reviews”. In 2006, he received the Presidential Early Career Award for Scientists and Engineers (PECASE) at the White House. That same year he also was awarded the Early Career Scientist and Engineer Award from the Department of Energy (DOE) Office of Defense Programs. In 2001 he received the Faculty Early Career Development (CAREER) Award from the National Science Foundation.