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Low Temperature Plasma Processing of Qubit Materials

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Quantum information science (QIS) has introduced a paradigm shift to sensing, communication and computation. The promising implications of QIS such as extending beyond classical sensing limits and overcoming currently computationally impractical problems have become a pressing concern for near future commercial competitiveness and national security. Quantum bits (qubits) are the elemental unit for QIS (e.g., analogous to transistors and classical bits), where sensors sometimes rely on single qubits to probe their local environments at the nanoscale while fault tolerant quantum computers might require millions to billions integrated together.

Advancing the fabrication science of quantum bits (qubits) is a necessary next step to realize QIS applications. Thin film processing is recognized by many companies and researchers as the most promising approach for manufacturing reproducible, large area (i.e., commercial scale), epitaxially defined materials for sensing applications to integration of millions of low error qubits for fault tolerant quantum computing (QC) in the foreseeable future. Reduction of manufacturing-induced atomic scale defects and maintaining yield will be key challenges. These fabrication requirements exceed the limits of present semiconductor processes, tools and foundational knowledge (e.g., of defect control) to achieve the needed atomic scale perfection at surfaces and interfaces.

Presently, there are many types of physical qubits being investigated in order to build near-term systems with 10s to 100s of qubits. Many of the leading technologies, including those used by Google, Intel, Global Foundries/PsiQuantum, Amazon, Alibaba and IBM, utilize IC chip manufacturing technology. Since low temperature plasma is so commonly used in chip manufacture, it is also essential in thin film-based qubit fabrication as well. But the processes of plasma-enhanced film deposition, etching, surface cleaning and so forth can generate defects such as undesired residual surface species, or surface roughness or maybe some trapped charge at a film interface. Interestingly, the increasingly atomic scale precision needed for 'conventional' chip manufacture is merging with the need for nearly defect-free processing for qubit fabrication. Meeting the qubit fabrication challenge will require a concerted multi-disciplinary effort spanning plasma science, materials science, surface science, and QC device science.

In this talk, we will first provide an introduction for those not familiar with qubits and then describe a series of examples of the importance, challenges and future opportunities of plasma in thin film-based qubit fabrication.

Biographies

Malcolm S. Carroll joined the semiconductor division of Bell Labs/Lucent Technologies at Murray Hill, NJ, which subsequently became Agere Systems in 2002 after completing his Ph.D. in Electrical Engineering at Princeton University. Part of the research at Bell/Agere resulted in a patent on epitaxial integration of germanium detectors with CMOS electronics, which was later used for a start-up company called Noble Peak Vision. He worked at Sandia National Laboratories from 2003-2018 becoming a distinguished member of the technical staff. During the time at Sandia National Labs, he founded and was the technical director for the silicon quantum computing program. This included contributions in MOS quantum dots and qubits utilizing the spin-orbit effect or single donors. He moved to IBM Quantum from 2019-2020 and worked on systems architecture and coherence in superconducting multi-qubit devices. He is presently a managing principal research physicist at the Princeton Plasma Physics Laboratory. He is also an adjunct professor at the University of New Mexico and Sherbrooke University.

Malcolm Carroll has been a first-or co-author on over 100 peer reviewed articles and 8 patents with greater than 2400 citations. He has co-founded several continuing international conference series in quantum computing and he has served as an external advisor in a number of different national and international capacities. He was also a Fulbright scholar at the Johannes-Guttenberg University of Mainz, Germany.

David B. Graves joined the University of California at Berkeley Department of Chemical Engineering in 1986 after receiving his PhD (Chemical Engineering) from the University of Minnesota. He retired from UCB in May 2020 and joined the Princeton Plasma Physics Lab as Associate Lab Director, effective June 1, 2020. He also has an appointment as Professor in the Department of Chemical and Biological Engineering at Princeton University, starting July 1, 2020.

David Graves is a fellow of the American Vacuum Society and the Institute of Physics and was the recipient of the Electrochemical Society Young Author Award, the NSF Presidential Young Investigator Award, the Tegal Plasma Thinker Award, and the 3rd annual Plasma Prize of the Plasma Science and Technology Division of the AVS. He was named the Lam Research Distinguished Chair in Semiconductor Processing at UC Berkeley for 2011-16. He received the Allis Prize for the Study of Ionized Gases from the American Physical Society in 2014 and the 2017 International Symposium of Dry Processes Nishizawa Award.