QUANTUM DOTS BASED RAD-HARD COMPUTING AND SENSORS

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Introduction: Quantum Dots (QDs) are solid-state structures made of semiconductors or metals that confine a small number of electrons into a small space. The confinement of electrons is achieved by the placement of some insulating material(s) around a central, well-conducting region. Thus, they can be viewed as artificial atoms. They therefore represent the ultimate limit of the semiconductor device scaling.

NASA Relevance: A survey of future deep space missions indicate a recurrent theme of the following technology needs: 1. Autonomous navigation and maneuvering, 2. Miniature *in situ* sensors, 3. Radiation and temperature tolerant electronics. QDs will provide the underlying computing and sensing capabilities to satisfy the above needs. To achieve autonomous navigation and maneuvering one needs algorithms and high performance computing. It is obvious that the computing HW in addition to being high performance need to be low power, low mass, radiation and temperature tolerant. The ultra-small dimensions and very high packing densities, already achievable in QD structures, provide the bases for the projection that QDs based computing will be 10^5 times better than conventional CMOS technology. Furthermore, QDs will enable lasers and infrared photodetectors operating in 2 to 5um wavelength. For these reasons, QDs will be at the heart of Miniature *in situ* sensors and lab on a chip. More important for deep space applications has been the finding that several of the optoelectronic devices with QDs in the active area show increased radiation tolerance [1-2]. Although, most of the current R&D focused in operating QDs base devices in room temperature, it is clear that the characteristics of these devices will improve in low temperature. Hence, QDs will play a key role in missions that will benefit from radiation & low-temperature tolerant electronics.

QD Applications of Relevant to Deep Space:

Sensor-optoelectronic detection and emission devices. Most atmospheric and planetary gases have strong absorption bands in the 2-5um wavelength range. Therefore, semiconductor laser diodes and detectors in this range are enabling technologies for detecting many organic and life-signature molecules. Research and development in this frequency range is specific to space science, and is not of great interest to the commercial sector. GaSb-based lasers are currently the choice for applications in this wavelength range, but they suffer from non-availability of high-quality substrates and immature growth processing technologies. On the other hand, there have been recent advances in the fabrication technology of both III-V semiconductor QDs and devices. Using the self-organized growth technique, InGaAs QDs on GaAs substrates have been exhibiting 3-D quantized confinement with sufficient material quality to obtain lasing. QDs promise several improvements in laser diode performance, including ultra-low threshold current density and temperature-insensitive threshold. GaAs-based QD lasers operating at 1.3um with a low threshold of 1.2 mA have recently been reported [3]. Temperature-insensitive low threshold has been obtained up to ~250K. Recently, InAs QDs of emission wavelength up to 2um have been demonstrated on InP substrates. We are developing long-wavelength (2~5um) InAsSb QD lasers on InP substrates. The formation of ternary InAsSb QDs will extend its emission wavelength beyond 2um.

Computing — logic/memory/computational devices. Several computational architectures based on QD arrays have been proposed in the past few years. Computing without transfer of charge (no current) provides the ultimate low power consumption [4]. Dense QD packing and low power properties along side of massively parallel and defect tolerant architecture[5} promise to provide extremely high performance computing, allowing for highly autonomous missions. While such computing systems has commercial relevance in terrestrial applications, NASA missions have the added requirement of radiation and temperature tolerant, which can be addressed in these technologies.

Design Tradeoffs: The solid-state-based confinement of electrons into a small spatial region can be implemented in a large variety of material systems and structural configurations. We focus on III-V semiconductor-based QDs due to their obvious advantage of co-integration into existing semiconductor technology. Even with this restriction, the exploration of the design space is an enormous task. Typical design parameters are QD compositions, sizes, doping, and confinement material. We therefore focused two of our task elements on this exploration:

1) Development and utilization of experimental nano-scale characterization technology [1-2].
2) Development of a comprehensive nano-scale electronic structure modeling and simulation tool [6].

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