

Scalar Atomic Defect-Based Solid-State Self-calibrating Magnetometer (3SM) for Space Plasma Analysis

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The Earth's magnetosphere is a system of multiple, co-located particle populations interacting via plasma waves. Things to understand are driving processes, radiation belt and ring current issues, auroral physics, internal plasma processes, and magnetosphere-ionosphere mapping issues. These plasma-physics processes enable the Earth's magnetosphere to evolve in response to temporal changes in the solar wind and they underlie the phenomena of space weather, which impacts spacecraft systems, astronauts, radio communications, and ground based electric-power grids[1].

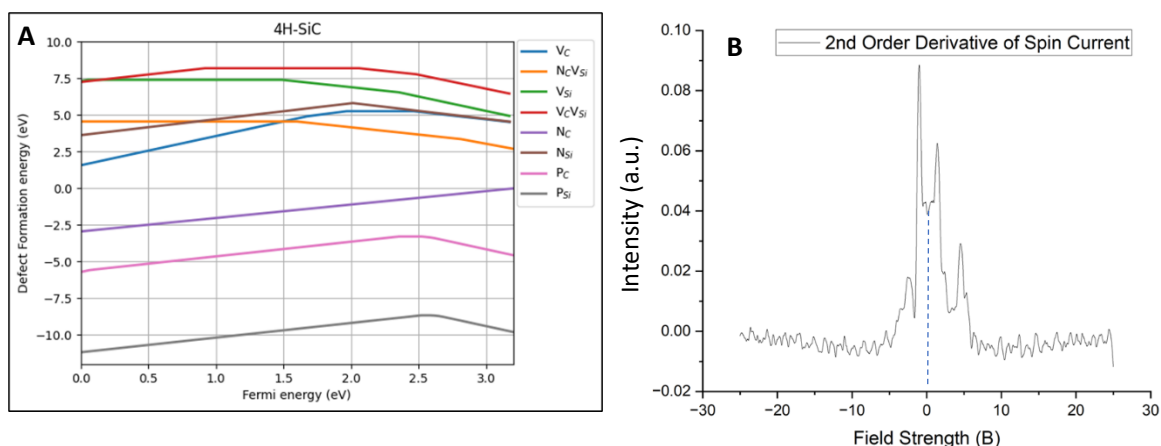
The objective of 3SM is to measure magnetic field strength and to calibrate the Vector Magnetometer (VM) device to maintain absolute accuracy during a mission. The 3SM features make the instrument preferably suited not only for the traditional role of scalar magnetometers as absolute references for the calibration of the on-board vector instruments, but also for extended operational capacities, such as higher frequency scalar measurements (of potential interest for magnetosphere studies for the low frequency part of the spectrum) or autonomous scalar / vector operations. Diamond has been the solid-state platform of choice for quantum device technologies for some time, however, it suffers from difficulties such as scalability, integration, and cost.

While the diamond platform is very useful for quantum technologies, further development is needed to make it viable. The material platform of choice for NASA Glenn's Quantum Sensing And Spin Physics (Q-SASP) is silicon carbide (SiC). This is due to the much higher industry development of the SiC material platform for high-power and high-temperature electronics. It leverages both the decades-long SiC development expertise and infrastructure at NASA Glenn and its growing capabilities in quantum metrology. To make SiC devices usable for quantum technologies such as quantum sources, a much deeper understanding of defects is needed. Q-SASP is developing quantum metrology capabilities to evaluate the energy structure, defect formation energy, band structure augmentation, generation/recombination rates, and limits of dipole-dipole coupling in non-metal implanted SiC devices. This can be achieved by analysis of zero-field splitting, low-field resonance, and singlet-triplet mixing through various forms of Electrically Detectable Magnetic Resonance (EDMR) and Near-Zero Field Magnetic Resonance (NZFMR) spectroscopy. This work will discuss recent system developments, device developments, computational modeling, and spectroscopy results and analysis of defects created by non-metal implantations in SiC devices.

The defect formation energies of V_{Si} , V_C , $V_C V_{Si}$, $N_C V_{Si}$, N_{Si} , N_C in 4H-SiC are previously reported values in other research [2]-[3]. The defect formation energies of P_{Si} and P_C were calculated in GPAW [fig 1A]. The basic underlying mechanism of the zero-field phenomenon is the mixing of singlet and triplet states [4]-[5]. In most spin-dependent transport, two electron spins are involved, and thus one must consider each of their interactions with the field. We investigated the electronic and magnetic properties of 4H-SiC and 6H-SiC. The defect formation energy helps us determine

what types of defects we are observing in the SiC EDMR experiment. They have very low formation energy (it is negative). The phosphorus substitution in 4H-SiC is a very stable defect.

The band diagrams provide us with vital information about how the electronic properties of SiC (such as band gap) change as we add non-metal defects. The zero-field splitting parameters allow us to study the inflection point in the NZFMR [fig 1B]. We clearly observed zero-field splitting. We also noted that the zero-field splitting remained constant with changing bias. We aspect it zero-field splitting to remain constant while the hyperfine and exchange interaction perturbations shift under the influence of an external magnetic field. This is the essence of quantum magnetometry and self-calibration.



A.) Defect formation energies in 4H-SiC calculated in GPAW B.) 2nd order derivative with inflection point at zero Gauss. In magnetometry the inflection point would stay at zero Gauss as it is a fundamental aspect of zero field splitting.

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