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Probing of radiation damage with light-emitting quantum defects in Silicon

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Irradiating a semiconductor with energetic particles gives rise to structural damage and defect formation via nonionizing energy loss processes. The build-up of stable radiation damage often proceeds via complex dynamic annealing processes, involving point-defect migration and interaction. This also occurs during the ion-implantation for electronic device fabrication and resulting defect structures depend on the density of collision cascades and the ion-beam flux. On the other hand, radiation-induced light-emitting defects, such as carbon-based defect complex of the G-center in silicon, have been regarded as promising quantum light sources for applications e.g. in quantum networking. However, the formation dynamics of these G-centers and the correlation between their optical linewidth broadening and atomic radiation disorder have rarely been studied. Here, we report on our study of the formation dynamics of G-centers in silicon for a series of proton beam flux conditions [1]. We compare the G-center optical properties characterized by time-resolved photoluminescence and observe a dose-rate effect on G center formation efficiency and optical line width. Furthermore, we perform ab initio electronic structure calculations, which provide insight into the atomic disorder induced inhomogeneous broadening by introducing vacancies, Si interstitials, and oriented strain fields in the vicinity of a G center. Our results can guide directions for the efficient formation of G centers for quantum applications. Moreover, our results indicate that the optical signal from G-centers enables atomic scale sensing and characterization of radiation damage resulting from ultradilute low-fluence irradiation, e.g., expanding capabilities for dark-matter searches.

References:

[1] W. Liu, et al., "Quantum Emitter Formation Dynamics and Probing of Radiation-Induced Atomic Disorder in Silicon", Phys. Rev. Appl. 20, 014058 (2023)

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