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### **Sub-bandgap absorptance in chalcogen-hyperdoped silicon<sup>1</sup>**

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It has been shown that optical doping with pulsed lasers can achieve non-equilibrium concentrations up to one atomic % of heavy chalcogens in silicon. Compared to intrinsic silicon, this material exhibits near-unity absorption of sub-bandgap photons and has potential use in silicon infrared photodetectors and high-efficiency photovoltaics. Successful application of this material, however, requires better understanding of the exact mechanism responsible for sub-bandgap absorptance. Using a variety of techniques, we probe the chemical structure of this material system. We find that the short range structure of the dopant atom is correlated to the amount of sub-bandgap absorptance. We also compare the structure of different dopant species (S and Se) as well as different hyperdoping mechanisms (fs-laser doping vs. ion implantation followed by pulsed laser melting). In conjunction with theoretical modeling of expected chalcogen defect states, we identify dominant structural characteristics related to the observation of sub-bandgap absorptance. Expanding on previous results, we demonstrate control of sub-bandgap absorptance through thermal processing. In addition to suggesting a method to engineer the optical properties of the material, this result provides further insight into the thermodynamics of formation of a possible dopant-related defect state. We compare the thermodynamics measurements to the dopant structural measurements and posit a model of sub-bandgap absorptance and defect dynamics. These results provide a better understanding of the phenomena of sub-bandgap absorptance in chalcogen-hyperdoped silicon and a pathway to explore other hyperdoped semiconductors.

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