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Exploiting broadband light-matter interactions using disordered photonic crystals for enhancing solar cell collection efficiencies

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In recent decades, thin-film technologies have emerged as front-runners in solar light harvesting for their highly-reduced material volume and cost. Absorption lengths exceeding film thickness restricts absorption, but this scale allows us to take advantage of state-of-the-art light-trapping and field enhancing techniques that increase photon lifetimes. One type of structure is the scattering entrance layer, generally using a rough film or engineered patterning. In this work, we study the scattering enhanced absorption due to photonic crystal (PC) nanowire and nanohole geometries (1 micron in height), and optimize each geometry using finite-difference time-domain (FDTD) techniques. These structures can trap light via coupling into leaky PC modes, strongly enhancing the photonic local density of states (LDOS) and light-matter interactions. We show that these structures are not only robust to different classes (positional and radial) and magnitudes of disorder, but that broadband absorption is improved by the disorder-induced induced broadening of PC modes. We also compare these effects between (crystalline) Si and GaAs. We find that GaAs, unexpectedly, does not show the same qualitative behavior in the presence of structural disorder, remaining relatively unaffected while Si experiences improvements upwards of 30%. Careful calculations and analysis of the LDOS (local density of photon states) shows that the higher natural absorption of GaAs broadens the PC modes; thus, GaAs remains robust to disorder, but does not have as much room for improvement, relative to Si for enhanced scattering.

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