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Micro/nanostructure engineering for light management in thin-film solar cells

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Optimum capture of the incident light through efficient photon management is considered a crucial requirement for realization of ultra-efficient photovoltaic devices. For this purpose, diffraction gratings have been applied for photon management in solar energy conversion. Specifically, due to the hexagonal arrangement of the grating structure, hexagonal gratings can be favorable in integrated optics since they occupy the least space compared to any other periodic arrangement. Here, our recent progress in development of nanostructured hexagonal diffraction gratings for application in light absorption enhancement in thin-film solar cells is presented. Leveraging the photon management ability of polystyrene nano-sphere arrays, the simplicity of the self-assembly fabrication process, and highly elastomeric properties of polydimethylsiloxane (PDMS), a novel stretchable transmissive hexagonal diffraction grating is introduced. Thanks to its unique flexible yet hexagonal structure, the proposed grating is capable of reproducible in-situ tuning of both diffraction efficiency and spectral range. The developed grating exhibits highly efficient and broadband light diffraction fairly independent of incident light polarization and angle of incidence while concurrently being able to achieve high diffraction efficiencies of about 80%. As a proof of concept, the proposed hexagonal diffraction grating is utilized for light absorption enhancement in colloidal quantum dot semiconductor thin-films. In addition, taking advantage of the same qualities of hexagonal arrangement induced by nano-sphere lithography, metallic reflective hexagonal diffraction gratings are also demonstrated to have a great potential for photon management through plasmonics. By careful engineering of the geometry of the gratings through controlling the size and the distance between grating components, both forward and backward propagating surface plasmon polaritons (SPPs) and localized surface plasmons (LSPs) were observed in a hexagonal diffraction grating for the first time. Simultaneous excitation of SPPs and LSPs demonstrated here can have a considerable impact on light absorption enhancement in nanostructured thin-film solar cells through both local and interfacial light confinement.

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