experimentally determined layer thicknesses and optical constants. In Fig. 5(c), branches corresponding to the TE and TM modes with the highest modal overlap with the a-Si:H are shown, folded back to the angular range of interest by taking diffraction by the two-dimensional periodic structure into account. The curves are superimposed over an intensity map of the relative enhancement of the EQE of the patterned cell compared to the randomly textured Asahi cell. Clearly, the pattern of dispersive bands observed in the EQE measurements agrees well with the calculated mode dispersion. In particular, the bands of enhanced absorption in the 700–850 nm range are well explained by the model, including the crossings at 740 nm and 770 nm. Deviations between measurement and calculation are attributed to small differences in optical constants and the fact that the calculation does not include surface corrugation and associated mode coupling. Additional spectral features observed in the EQE spectra could possibly be associated with absorption due to local field enhancements in the nanostructures. The measurement clearly shows that for these wavelengths, coupling to modes guided by the a-Si:H layer is responsible for increased absorption in the cell. Calculations show a high density of modes in the spectral range 550–650 nm where the EQE of the patterned cell exceeds that of the randomly textured Asahi substrate. The fact that in this region no sharp features are observed in the measurements is due to the large number of modes present, which are strongly broadened because of large absorption of a-Si:H in this spectral region. Although similar modes may be observed for patterned dielectric particles, the scattering cross section of the metal nanostructures increases coupling to the guided modes, further enhancing the photocurrent.

5. Conclusion

In summary, we have demonstrated ultrathin (160 nm) a-Si:H solar cells with efficient light trapping by a nano-engineered plasmonic back reflector. Light is scattered strongly from the nanopatterned metal back contact into guided modes of the cell, enhancing the photocurrent for a given cell thickness by enhancing the coupling to the modes. Similarly, the same photocurrent can be achieved at a reduced cell thickness, with a concomitant increase in open circuit voltage (and potential for increased long-term stability). We demonstrate that nano-engineered cells show light trapping that is enhanced beyond that of a randomly textured cell. This new design is not strictly relevant to a-Si:H based devices, but may be broadly applicable to other common thin-film solar cell materials systems such as polycrystalline Si, CdTe, and $CuIn_xGa_{1-x}Se_2$. This result can directly impact the attainment of economically competitive and scalable renewable energy from thin-film solar cells.

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