Nanoimprint Method for All-Inorganic Resist for Photovoltaic Light-Trapping

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Imprint lithography is an attractive micro- and nano-patterning solution for solar energy conversion applications, because low incident power density means that large patterned areas are needed. Diffractive light trapping in thin-film photovoltaics is one such example: a reflective diffraction grating at the backside of a thin semiconductor layer couples transmitted light into waveguide modes, thus enhancing the optical layer thickness. Light trapping is particularly important in thin crystalline silicon photovoltaics, because the indirect semiconductor bandgap results in long absorption lengths for red and near-infrared light.

Direct imprinting of a dielectric precursor film as an integral device component can reduce costs. However, previous approaches with sol-gel chemistry presented several problems due to the high post-imprint annealing temperatures required to eliminate organic additives. These anneals yield porous films with lower refractive indices than the bulk material, and the high temperatures may not be compatible with other photovoltaic device components.

In this paper we present a nanoimprint method for an all-inorganic resist, aluminum oxide phosphate (AlPO). This resist is free of organic additives, water-based, environmentally benign, and has recently been demonstrated to yield amorphous gate-dielectric films with near-PVD quality. Using various epoxy and flexible polymer replica molds, we demonstrate defect-free imprinted areas of more than one square centimeter, with feature sizes down to 10 nm. Here, we also present preliminary results for high-refractive-index materials and discuss the challenges of integrating imprinted dielectric layers in thin-film photovoltaic devices in both superstrate and substrate configurations.

Fig. 1 shows imaging results from imprinted AlPO gratings designed for photovoltaic film-devices. Line gratings down to 139-nm period have been fabricated. Fig. 2a shows a schematic of diffractive light trapping for photovoltaics. The layer denoted “dielectric” is fabricated by imprinting ceramic precursor resists and overcoated by an Ag reflector layer. Fig. 2b shows measured optical absorption data for a 25-micron wafer, used as a model system. The figure compares a grating reflector with light trapping and a flat reflector as reference. The measured absorption enhancements (photons in AM 1.5 standard solar spectrum absorbed) of up to 15% due to light trapping are consistent with computer simulations we performed in parallel with the experiments. As shown, this 25-micron wafer with grating has an apparent absorption edge equivalent to a wafer twice as thick as one that has no grating. The extrapolated absorption enhancement for 2-micron thick Si films is in the range of 50–80% for one-dimensional and two-dimensional gratings, which is very promising.

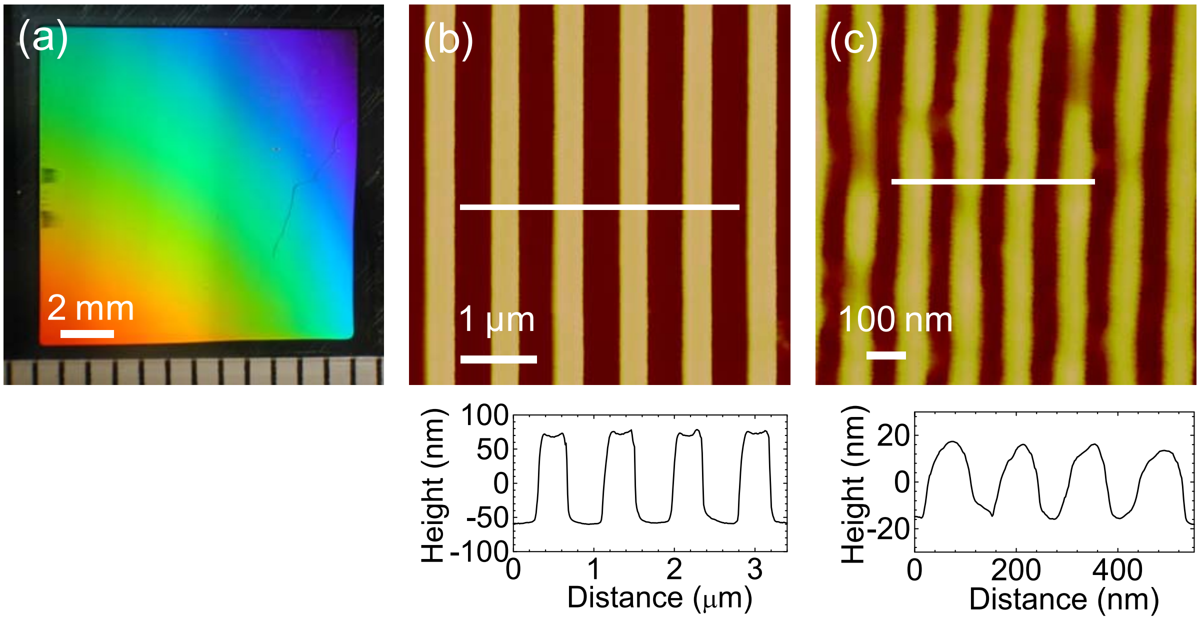

Figure 1 Imprinted aluminum oxide phosphate resist films: (a) optical micrograph of 833-nm period line grating (the resist was coated with 60 nm silver to enhance reflectivity); (b) AFM topography and profile (along white line) of 833-nm period line grating; (c) AFM topography and profile (along white line) of 139-nm period line grating.

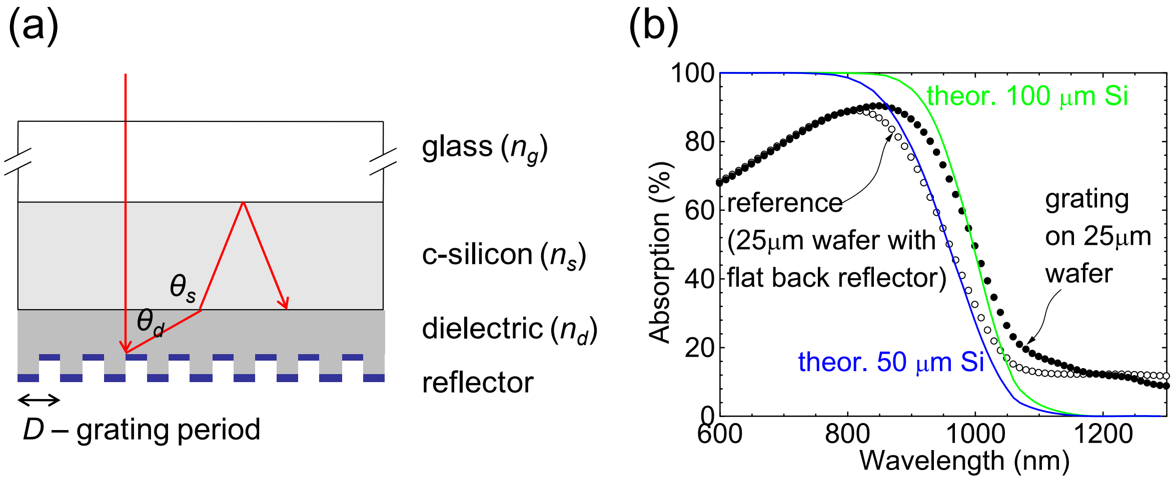

Figure 2 (a) Schematic of diffractive light trapping in a thin crystalline silicon film device: oblique light rays are coupled into waveguided modes to enhance optical film thickness; (b) measured optical absorption edge in a 25-μm thick silicon wafer, with and without 833-nm period ceramic back grating overcoated with Ag; solid curves are theoretical absorption of Si wafers of labeled thickness.