ARTICLES

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Large-scale, adhesive-free and omnidirectional 3D nanocone anti-reflection films for high performance photovoltaics

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Abstract: An effective and low-cost front-side anti-reflection (AR) technique has long been sought to enhance the performance of highly efficient photovoltaic devices due to its capability of maximizing the light absorption in photovoltaic devices. In order to achieve high throughput fabrication of nanostructured flexible and anti-reflection films, large-scale, nano-engineered wafer molds were fabricated in this work. Additionally, to gain in-depth understanding of the optical and electrical performance enhancement with AR films on polycrystalline Si solar cells, both theoretical and experimental studies were performed. Intriguingly, the nanocone structures demonstrated an efficient light trapping effect which reduced the surface reflection of a solar cell by 17.7% and therefore enhanced the overall electric output power of photovoltaic devices by 6% at normal light incidence. Notably, the output power improvement is even more significant at a larger light incident angle which is practically meaningful for daily operation of solar panels. The application of the developed AR films is not only limited to crystalline Si solar cells explored here, but also compatible with any types of photovoltaic technology for performance enhancement.

Key words: antireflection; crystalline Si solar cells; flexible film

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Supplementary Information

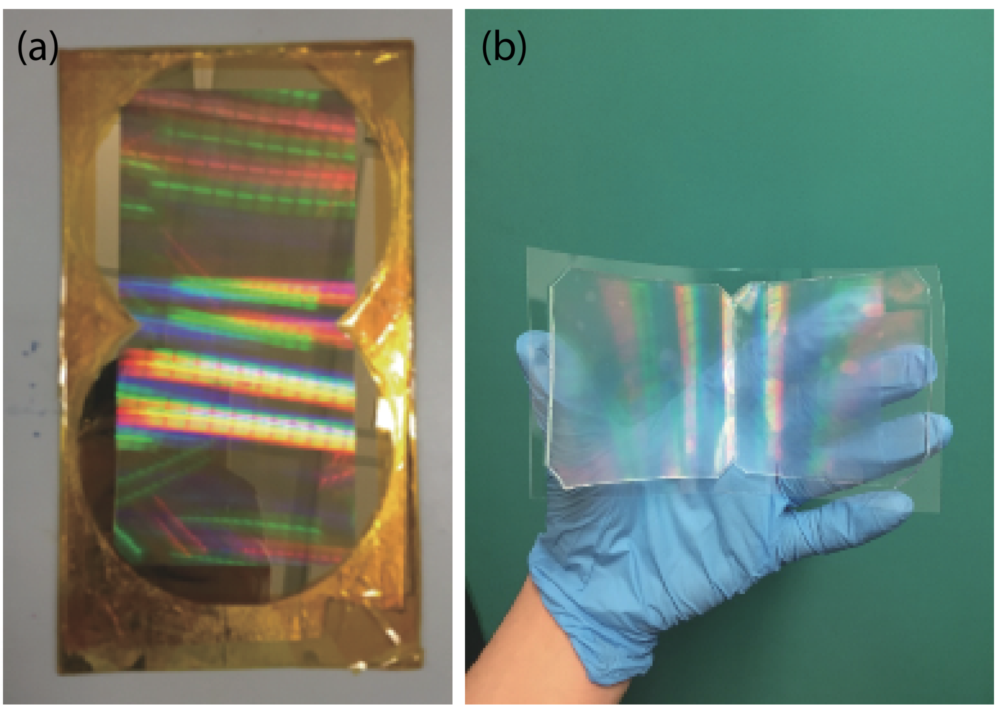

Fig. S1. (Color online) (a) The photograph of two wafer size mold with stitching method. (b) The photograph of flexible AR film attached on polycarbonate film.

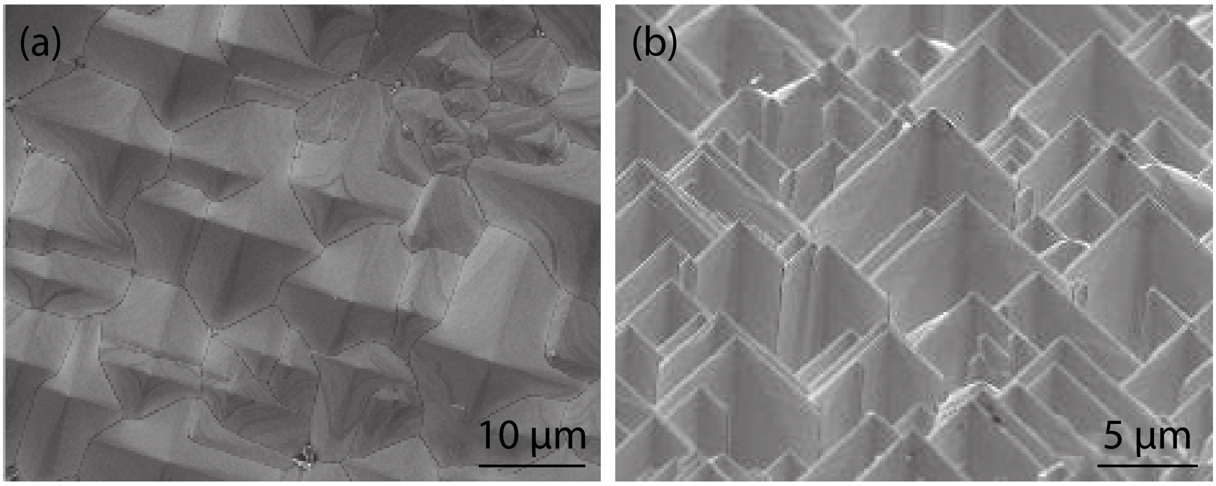

Fig. S2. (a) The top views of SEM images of the c-Si solar cell. (b) The cross-sectional SEM images of the c-Si solar cell.

Table S1. Angular-dependent electrical performance measurement of the bare c-Si, epoxy-encapsulated and AR film-attached device.

Angle (Degree)		0	10	20	30	40	50	60
J_{sc} (mA/cm^2) from solar simualtor	Bare c-Si	27.19	26.42	24.48	21.98	19.13	15.82	12.36
	Epoxy c-Si	27.18	26.48	25.15	23.09	20.22	17.20	13.38
	AR film c-Si	28.56	27.52	26.23	24.22	21.74	18.81	15.32
V_{oc} (V)	Bare c-Si	0.642	0.640	0.639	0.631	0.645	0.636	0.622
	Epoxy c-Si	0.654	0.644	0.637	0.634	0.631	0.625	0.613
	AR film c-Si	0.652	0.642	0.640	0.633	0.632	0.626	0.620
Fill factor	Bare c-Si	67.0	67.1	67.5	68.0	69.4	69.8	70.6
	Epoxy c-Si	66.9	66.7	66.9	67.3	68.2	68.9	69.7
	AR film c-Si	66.7	66.0	66.9	66.8	67.7	68.4	69.5
Efficiency (calibrated efficiency) (%)	Bare c-Si	11.7	11.3(11.5)	10.5(11.2)	9.4(10.9)	8.6(11.23)	7.0(10.9)	5.4(10.8)
	Epoxy c-Si	11.9	11.4(11.6)	10.7(11.4)	9.9(11.4)	8.7(11.4)	7.4(11.5)	5.7(11.4)
	AR film c-Si	12.4	11.7(11.9)	11.2(11.9)	10.2(11.8)	9.3(12.1)	8.1(12.6)	6.6(13.2)

Table S2. Angular-dependent daily energy output measurement of the bare c-Si, epoxy-encapsulated and AR film-attached device.

Daytime (h)	Bare c-Si	Epoxy c-Si	AR film c-Si
8	54	57	66
8.66	70	74	81
9.33	86	87	93
10	94	99	102
10.66	105	107	112
11.33	113	114	117
12	117	119	124
12.66	113	114	117
13.33	105	107	112
14	94	99	102
14.66	86	87	93
15.33	70	74	81
16	54	57	66
Total energy output (Wh/m^2)	774.39	797.07	844.42
Improvement (%)	—	2.93	9.04