Supporting Information

Wafer-Scale Nanostructured Black Silicon with Morphology Engineering via Advanced Sn-assisted Dry Etching for Sensing and Solar Cell Applications

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1 Photograph, SIMS and TEM data of the as-grown GeSn on Si.

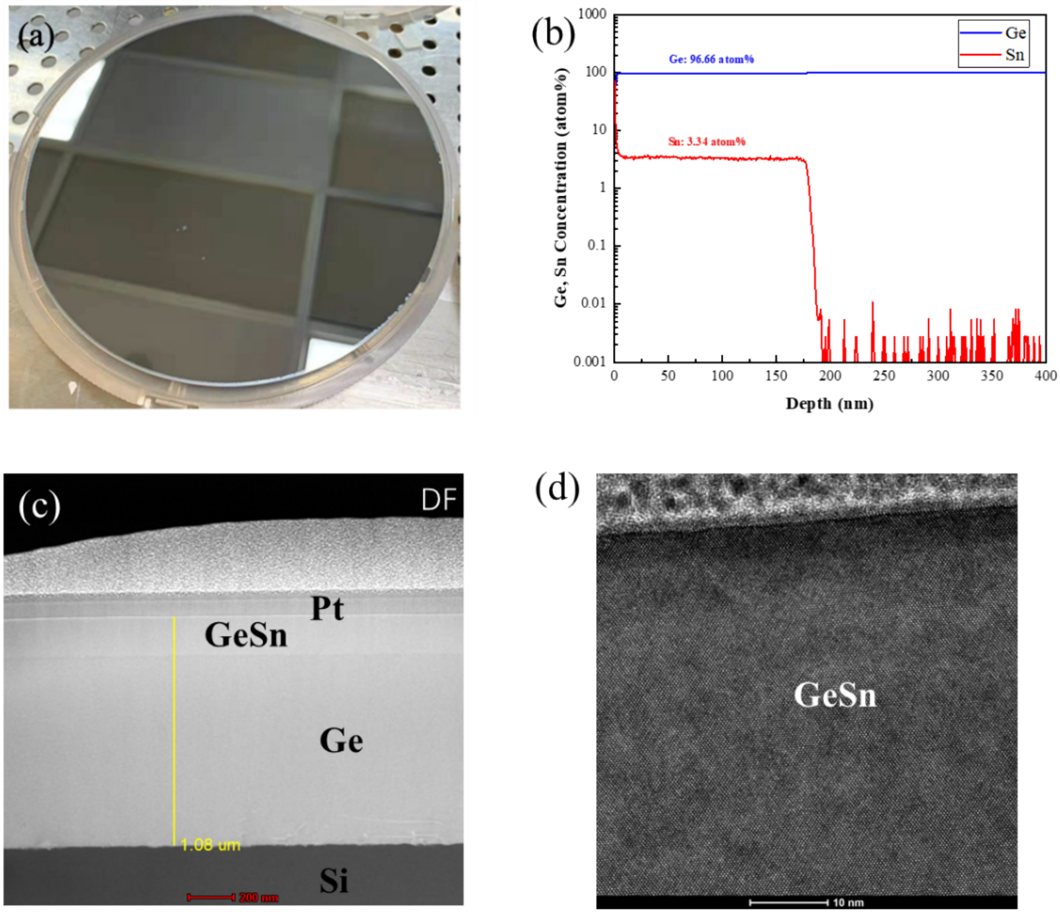

Fig. S1 (a) Photograph, (b) SIMS, and (c) and (d) TEM data of the as-grown GeSn on Si. The photograph in (a) shows the 6-inch GeSn/Ge/Si wafer has a shiny surface, indicating the absence of Sn segregation. The SIMS in (b) shows the GeSn layer has a uniform Sn-content of ~ 3% with a thickness of ~180 nm. The TEM images in (c) and (d) show the high-quality and single-crystalline of the GeSn film.

2 Additional SEM images of the etched Si before HCl solution treatments.

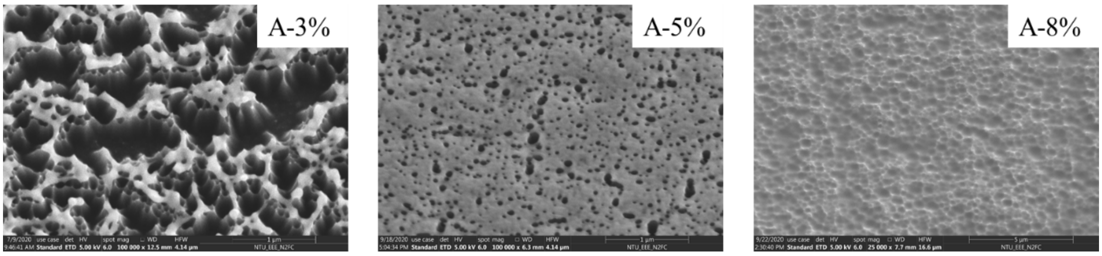

Fig. S2 Series A samples with the Sn-content of 3, 5, and 8%. The ICP/RF power, pressure, O_2 flow rate, and chamber temperature of the ICP-RIE process are 400/50 W, 25 mtorr, 40 sccm, and 0ºC respectively. The higher the Sn-content, the thicker the SnO_xF_y passivation layer formed. The thick SnO_xF_y layer decreases the etching rate.

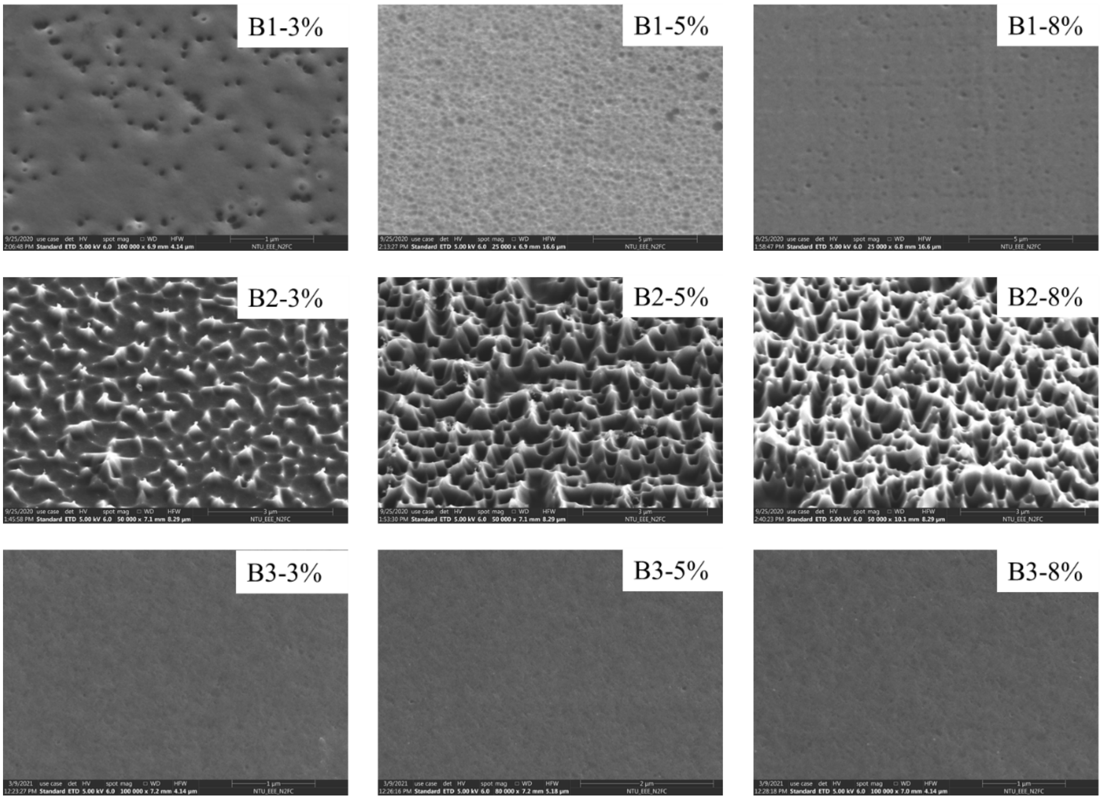

Fig. S3 Series B1, B2, and B3 samples with the Sn-content of 3, 5, and 8%. Compared to series A (400/50 W), the ICP/RIE power was changed to 200/25(Series B1), 800/100 (Series B2), and 1600/200 W (Series B3). A higher ICP/RIE power promotes the GeSn film's etching due to the increase of the average ion energy. Due to the extremely high power of series B3, only reflected Si substrates exist as the masked SnOxFy layers have been fully consumed.

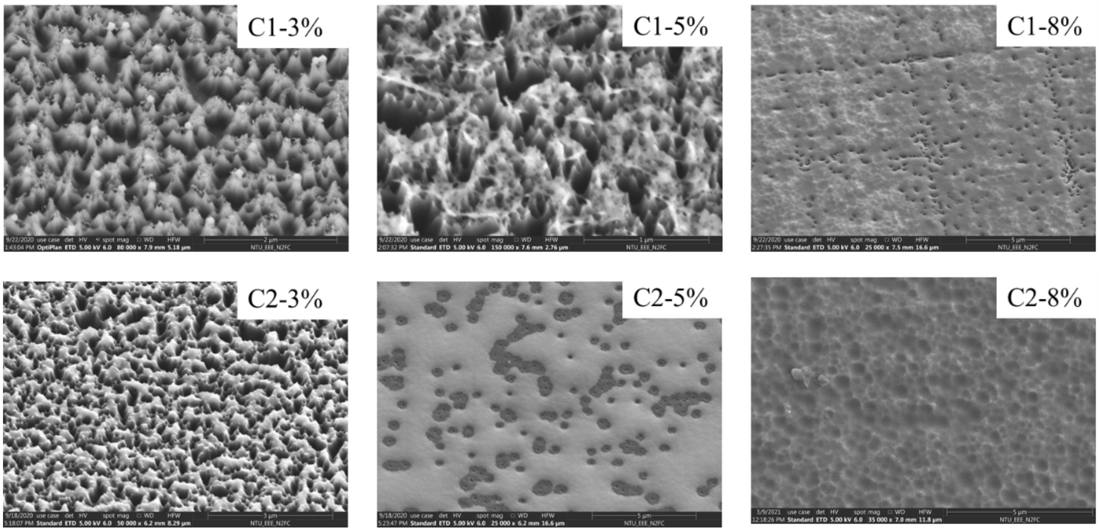

Fig. S4 Series C1, and C2 samples with the Sn-content of 3, 5, and 8%. Compared to series A (25 mtorr), the pressure was changed to 15 (Series C1) and 35 mtorr (Series C2). A low pressure promotes the etching of the GeSn film due to the increase of the mean free path length of the ions and the average ion energy.

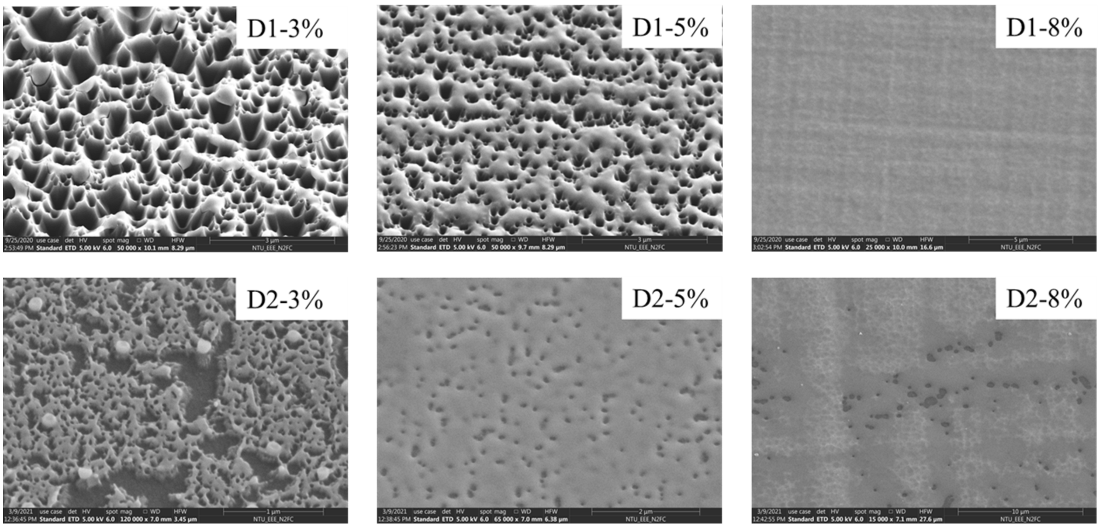

Fig. S5 Series D1, and D2 samples with the Sn-content of 3, 5 and 8%. Compared to series A (40 sccm), the O_2 flow rate was changed to 10 (Series D1), and 80 sccm (Series D2). The high O_2 flow rate promotes the formation of a thick SnO_xF_y layer, which hampers the sample's etching. Thus, it is hard to from the b-Si for the series D2 etching conditions, especially for the high Sn-content samples.

3 Etched depth of Si samples covered with different Sn-content GeSn (Series A).

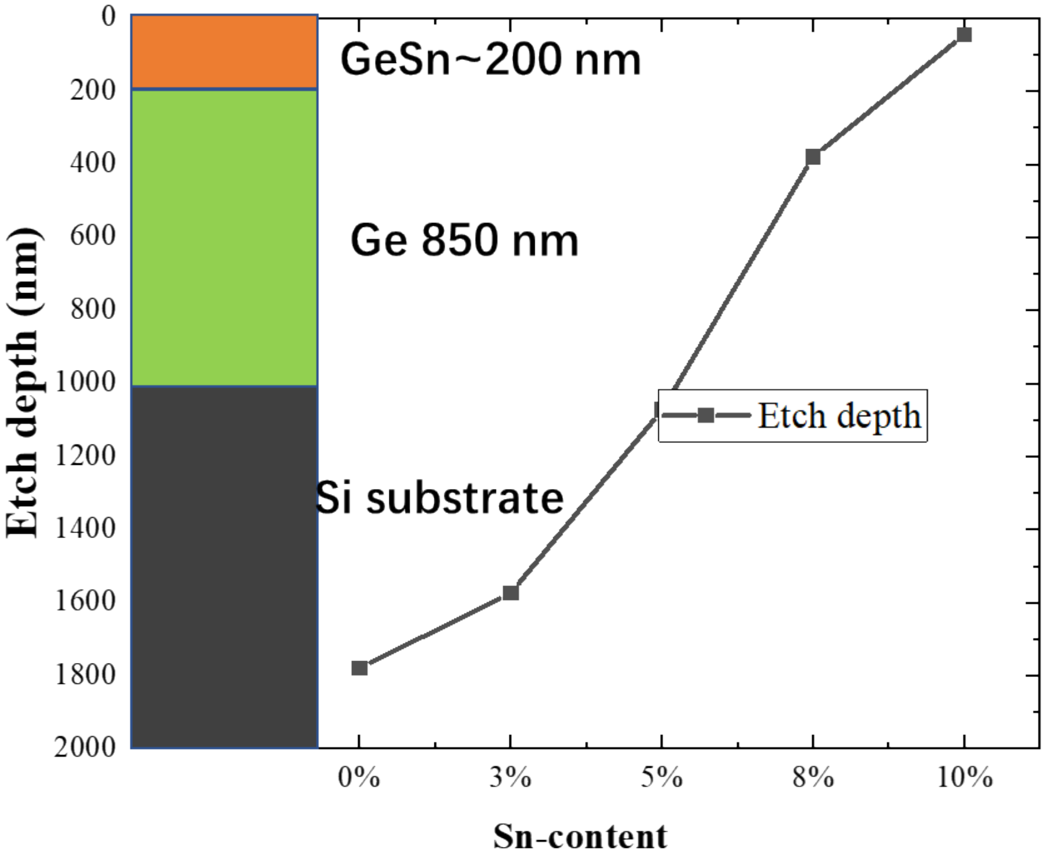

Fig. S6 The measured etched depth of GeSn film covered Si samples after the ICP-RIE etching for series A. The results show the protective effect of the GeSn layer during the dry etching—the higher the Sn-content, the thicker the SnO_xF_y passivation layer formed.

4 Additional FDTD simulation results of the nanowire-structured black silicon

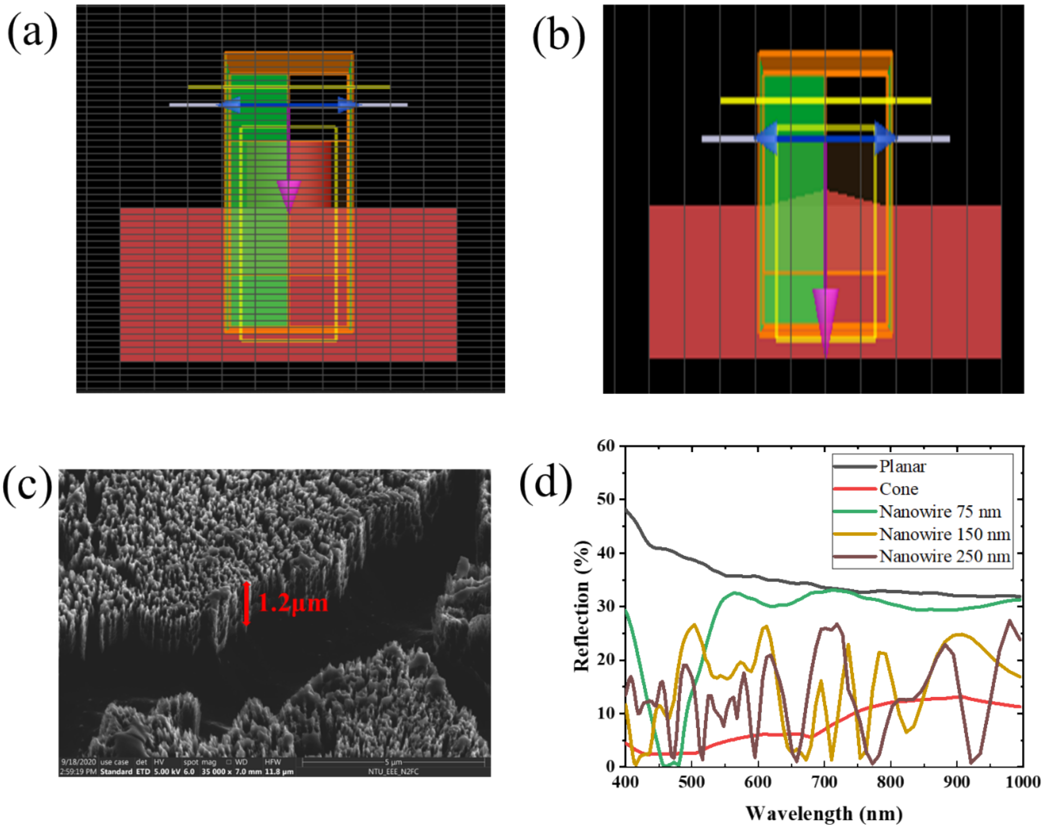

Fig. S7 Simulation of the reflections of the nanowire and nanocone Si.(a) and (b)The geometry (not to the scale) modeled of the nanowire and nanocone in this study; (c) The tilted SEM view of the nanowires, which shows the longest NW are >1μm;(d) Simulation of the reflections of the nanowire Si with the nanowire diameter between of 75,150 and 250 nm. For our simulation, the period of the nanostructures (including nanopore, nanocone and nanowire) was all set to 0.7 μm. The height (or length) of the nanowires was all set to 1.0 μm and the diamteter of the nanowire was changed. The same as the main text, the nanocone has a pyramid structure with the height of 250 nm. As shown in 4d, compared to the nanocone structures, the reflections of the nanowire Si are high that the nanocone Si, except for some special wavelengths (e.g., 450-470nm for the 75 nm diameter nanowire). Due to the uniform diameter of the nanowire structure, the guided resonance modes occur in some particular energies (wavelengths) and are conducive to broad anti-reflection as the nanocone Si.

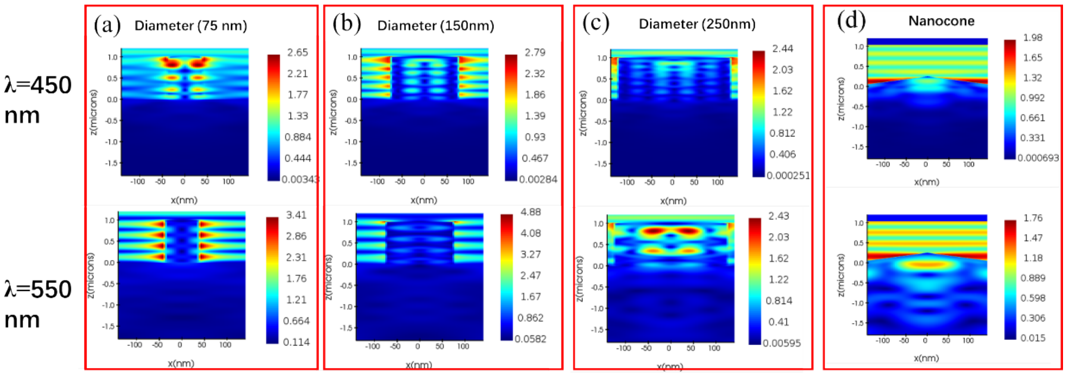

Fig. S8 Steady-state of light intensity distributions for (a)-(c) nanowire, and (d) nanocone Si surfaces at the wavelength of 450 (top) and 550 (down) nm, respectively. The distributions of electric field (|E|) show that guided resonance modes occur on the 75 nm diameter thin nanowires at the wavelength near 450 nm, which results in high light absorption. However, the absorption of the 75 nm diameter nanowires is low when the wavelength is at 550 nm. On the contrary, wide nanowires have a higher light absorption at 550 nm and lower light absorption at 450 nm. As the nanocone structures have a broad anti-reflection effect, the light absorption at 550 and 450 nm are high.