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High-Performance Lithium-ion Battery Anode Based on Core-Shell Heterostructure of Silicon-Coated Vertically Aligned Carbon Nanofibers

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This study reports a high-performance hybrid lithium-ion anode material using coaxially coated Si shells on vertically aligned carbon nanofiber (VACNF) cores. The unique "cup-stacking" graphitic microstructure makes VACNFs a good Li^+ intercalation medium and, more importantly, a robust brush-like conductive core to effectively connect high-capacity Si shells for Li^+ storage. The vertical core-shell nanowires remain well separated from each other even after coating with bulk quantities of Si (equivalent to over 1.5 μm thick solid films). This open structure allows the Si shells to freely expand/contract in the radial direction during Li^+ insertion/extraction. A high specific capacity of 3000-3650 $mAh(g_{Si})^{-1}$, comparable to the maximum value of amorphous Si, has been achieved. About 89% of capacity is retained after 100 charge-discharge cycles at C/1 rate. After long cycling, the electrode material becomes even more stable, showing invariant Li^+ storage capacity as the charge-discharge rate is increased by 20 times from C/10 to C/0.5 (or 2C). Surprisingly, the measured Li^+ insertion/extraction capacity increases as the rate is further increased to $\sim$8C. The short diffusion path length for Li^+ across the thin Si shell is the key to facilitate the fast electrochemical reaction. The ability to obtain high capacity at significantly improved power rates while maintaining the extraordinary cycle stability demonstrates that this novel structure could be a promising anode material for high-performance Li-ion batteries.