Tin Seeded, PECVD Grown Silicon Nanowires
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Renewable Energy MRSEC, NSF DMR-0820518

Silicon nanowires are potentially transformative photovoltaic materials. Nanowire arrays are commonly synthesized using gold seeded vapor-liquid-solid (VLS) growth. Gold, however, can damage silicon’s electronic properties and growth temperatures are too high for low cost substrates. Here silicon nanowires were grown from benign tin seeds at much lower temperatures using plasma enhanced chemical vapor deposition (PECVD). Control of wire radial and transverse growth rates was demonstrated.

Semiconductor nanowires offer size tunable properties and quantum mechanically modified carrier dynamics through 2-d confinement while the third dimension provides a topology for photoexcited charge collection. They also enable novel device architectures in which layers are optically thick while charge separation of photoexcited carriers can occur over a short distance perpendicular to the direction of the incident light. This can minimize the effect of defects. Silicon and silicon alloy nanowires are of particular interest because of the wealth of existing expertise in silicon processing and potential compatibility with existing silicon based PV materials like amorphous and nanocrystalline silicon. The high elemental abundance of silicon and low toxicity are added benefits.

The most commonly explored silicon nanowire synthesis approach involves chemical vapor deposition using a metal seeded vapor-liquid-solid (VLS) process. Several issues exist with current VLS growth. First, the most commonly used seed is Au which is a known lifetime killer in silicon. In addition, Au has high solubility for Si, Ge, and dopants. This gives these elements long residence times in the seed before they are incorporated into the wire so that abrupt longitudinal junctions are not possible. Finally, for reasonable growth rates the CVD growth temperature is often 600°C or more. This is incompatible with many low cost substrates like soda lime glass.

We have demonstrated PECVD growth of silicon nanowires using Sn seeds. As a column IV element, Sn is isovalent with Si and should have less effect on minority carrier lifetime than gold while not doping the Si. In addition, Si solubility in Sn is extremely low allowing very abrupt junctions. While this makes Sn an ideal seed, prior reports of using Sn as a seed are almost nonexistent. The upper two panels show wires grown for 2 minutes and 20 minutes at 400°C using silane diluted in hydrogen and typical growth conditions. The wires prepared in our study have crystalline cores and tend to grow in the \( <11\overline{1}> \) (bottom right panel). We have also demonstrated nanowire formation directly on SiO₂ coated glass, through reduction of the oxide in a hydrogen plasma to form Sn seeds. This is particularly interesting for the ultimate low cost processing of nanowire solar cells. By creating reactive radicals from the source gas, PECVD in conjunction with the very low melting point (232°C) of the Sn seed results in enhanced VLS growth rates and we observe nanowire growth at temperatures below 300°C. A critical question concerns the effect of the plasma on the relative VLS rates (longitudinal) and vapor-solid (VS) growth rates. VS growth leads to radial growth of the wires. We find that VS growth does occur and wires often show an exterior layer of polycrystalline silicon (visible in the upper right image). The VLS and VS rates can be controlled, however, by changes in growth conditions (bottom graph). A talk on this work was presented at the Fall 2009 Meeting of the MRS and a paper is in preparation.