Semiconductor Nanowires for Thermoelectric Devices

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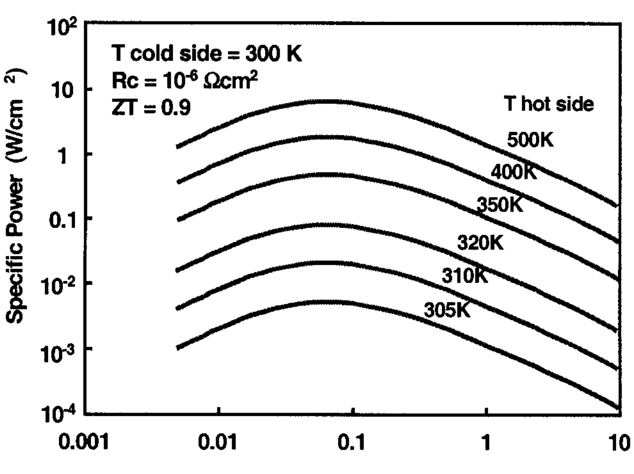
Miniaturization of electronic devices is of great interest for several applications; it is of particular interest in development of instruments for space research because of the strict limitations on device mass and volume growing out of limitations on power on spacecraft. Thermoelectric devices may be used both for generation of primary power from heat sources and by harvesting waste heat for additional power generation. In addition, as electronic devices become smaller and electronics are positioned in greater density, needs for increased cooling may develop.

For the past several years, approaches to miniaturization of thermoelectric devices for cooling and for power generation have been studied at the Jet Propulsion Laboratory [1]. As shown in the following plot of thermoelectric generator performance, the specific power of a device depends on the leg height, with a maximum at 50-60 μm.

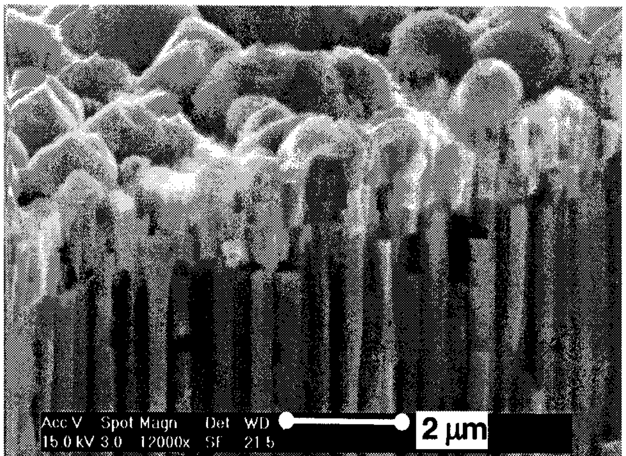


Research at JPL has developed approaches to fabricating devices with legs 10 μm diameter and

Recent work in thermoelectric theory has predicted that the efficiency of a thermoelectric device can be increased by a factor of ~3 if the leg diameter can be decreased to a size at which quantum confinement effects will occur [2,3]. Nanowire thermoelectrics of ~ 10nm diameter will increase performance efficiency through enhanced charge carrier mobility by quantum confinement effects. In addition, the high aspect ratio of the wires (10 nm x 20-50 μm) will assist in maintaining a large ΔT at low heat flux, further increasing generator capability. For such devices, the nanowires are contacted in bundles of ~ 10 μm, but each nanowire is distinct.

Nanowires have been grown in alumina templates with pore diameters of 100 nm and 40 nm. The photograph shows n-type Bi_2Te_3 nanowires 100 nm x 40 μm after the alumina has been removed. The thermoelectric properties of these wires are very good, with a measured Seebeck coefficient of -125 μV/K.

This paper will discuss electrochemical deposition of nanowires and the conditions necessary for forming 10, 40 and 100 nm nanowires.



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50 μm high. 10,000 legs can be contained in 1 cm^2, and connected electrically in series and thermally in parallel, to give an open circuit voltage of 1 -10 V and ~ 1 W power. The entire device can be built up by electrodeposition of both n- and p-type materials plus diffusion barriers and contacts in templates made with photoresist. n-type Bi_2Te_3 and p-type $Bi_{2-x}Sb_xTe_3$ have been deposited with good morphology and good thermoelectric properties. Such microdevices are estimated to operate with an efficiency of 2.5-3.0%.

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