Interface dominated thermal transport and dissipation characteristic of Si nanowire devices

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Abstract

The rapid increasing of power density in nano-devices, such as transistor, chemical sensors and thermoelectric devices, has generated a universal demand on thermal management at the nanoscale. However, the dramatically reduced device dimension makes thermal transport and dissipation more and more dominated by various interfaces that exist in devices, to which thermal characterization can hardly be applied. In this work, we use 3-omega method to determine thermal dissipation characteristic of Si nanowire under different length scale to reveal interfacial effects. At the sub-micrometer nanowire length, phonon transport becomes ballistic and only interface dominated thermal resistance is revealed. Using this method, thermal contact interfaces of Au/Si, Pt/Si, that has Debye temperature mismatch, and those annealed ones with silicide alloying are compared.

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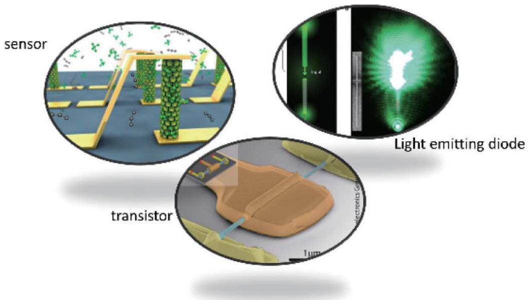
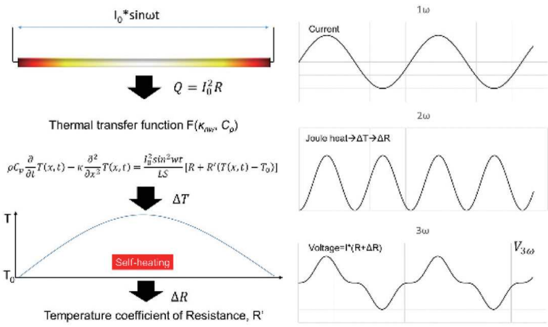
Background

Nanowires have gain lots of research interests in transistors, light emitting diodes, thermoelectric, photosynthesis and sensor devices. Due to the ultrasmall volume of nanowire, it is easily heated up by a tiny driven current. Knowing the real time temperature along nanowire becomes essential to predict nanowire performances. Many research have been focused on the examination of thermal transport in nanowires, whereas the thermal interface to nanowire has rarely been considered.

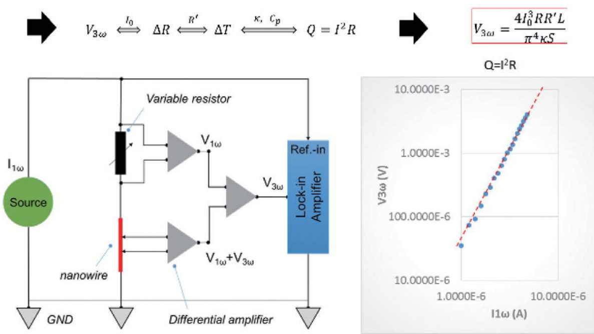


3ω method for thermal characterization

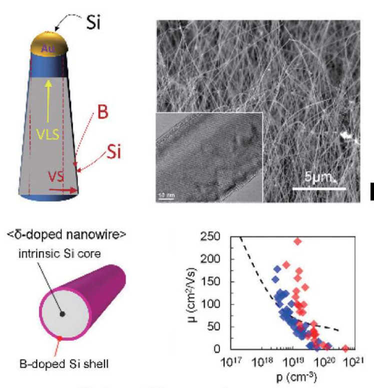
• Principle of 3ω method for thermal conductivity measurement



• 3ω system and the measurement

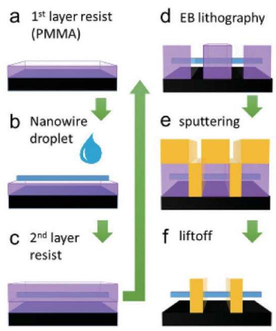


Material and Device

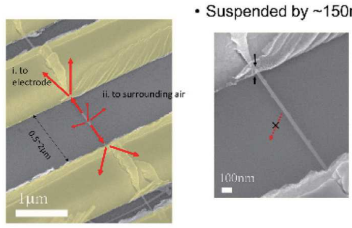


• High mobility nanowire

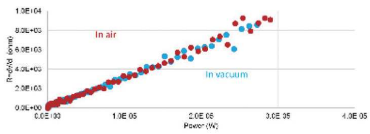
• EB lithography process for a suspended nanowire device



• Suspended by ~150nm



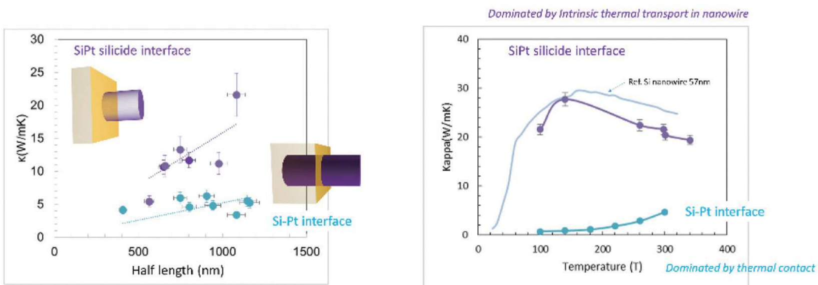
• Self-heating is independent on the atmosphere at sub micrometer



Result and Discussions

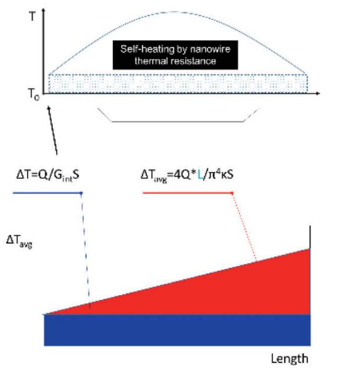
• Measurement results on Si nanowires

• Pristine sample versus thermal annealed sample



• Length dependent thermal conductivity are observed

• With the presence of thermal contact resistance



• The shorter the nanowire, the more dominant the thermal interface for the self heating effect

Summary

We studied the thermal transport in suspending Si nanowires by the 3ω method, and we found that the non-ideal thermal contacts to Si nanowires are dominating the thermal dissipation in Si nanowires. Forming of silicide thermal contact is very helpful for device cooling, while the pristine interface may be applied to thermal rectifying devices.