Scientists demonstrate effect of confining dielectrics on semiconductor nanowire conductivity

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Researchers at the Harvard School of Engineering and Applied Sciences (SEAS), in collaboration with researchers from Worcester Polytechnic Institute (WPI), have demonstrated, for the first time, that the activation energy of impurities in semiconductor nanowires is affected by the surrounding dielectric and can be modified by the choice of the nanowire embedding medium.

The finding, published in the April 6 issue of Applied Physics Letters, helps to confirm the "dielectric confinement effect", a key phenomenon in doping and conduction in nanostructures proposed by L. V. Keldysh in 1979. The dielectric confinement effect influences conductivity by changing the activation energy of dopants. Understanding the phenomenon has implications for improving the design of semiconductor nanowires as electronic devices, such as in the case of gas or liquid substance detectors.

"The demonstrated effect sets in as circuit dimensions shrink, which makes the material more sensitive to external conditions," explains lead author Venkatesh Narayanamurti, John A. and Elizabeth S. Armstrong Professor of Engineering and Applied Sciences and Professor of Physics.

Surfaces act like partial mirrors reflecting inner charges, and thus, an image charge in the mirror affects the energy of the real charge. When the surface is far, the mirror image is far and its influence is negligible. But as structures enter the nanometer scale the mirror draws in, making it possible to manipulate the conduction from the outside.

In the experiments, co-author Joonah Yoon, a graduate student at SEAS, coated GaN nanowires with silicon oxide to modify the strength of the surface mirror. The dopant activation energies were obtained from the temperature dependence of the nanowire conductivity. The dominant term of the activation energies extracted out of the data was found to vary inversely with the radii of the nanowires, confirming a previous theoretical prediction.

Further, detailed calculations using finite element method, carried out by graduate student Alexi Girgis of WPI, were used to iteratively solve the wave functions and energies of conduction electrons and accounted for the induced surface charges. The inverse radius dependence turned out to be a good approximation only for certain range of wire sizes.

"Our key finding was that devices made with nanowires, such as nanowire field-effect transistors, require imaginative design of the materials, the surrounding dielectric, and the operating voltage bias to take into account dielectric confinement effects," says Narayanamurti.

Previously, the effects of dielectric confinement have been investigated theoretically for the role they play in defining the optical properties of nanostructures, such as exciton binding energies, while the impact on electrical characteristics has largely been neglected partly due to the misconception that the relevant length scale still falls into the "classical" regime.

The present work opens up the general prospect of dielectric confinement engineering, or a way to exploit and optimize the performance of nanowire electronic and optoelectronic devices.

Source: Harvard University (news : web)