

In-situ propagation of metal phases in germanium nanowires observed by transmission electron microscopy

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Semiconductor nanowires (NWs) are promising candidates for many device applications ranging from electronics and optoelectronics to energy conversion and spintronics. However, typical NW devices are fabricated using electron beam lithography and therefore source, drain and channel length still depend on the spatial resolution of the lithography. In this work we show fabrication of NW devices in a transmission electron microscope (TEM) where we can obtain atomic resolution on the channel length using in-situ propagation of a metallic phase in the semiconducting NW. The corresponding channel length is independent of the lithography resolution. We show results on semiconducting NW devices fabricated on two different electron transparent Si₃N₄ membranes: a calibrated heater chip from DENs solution [1] and a homemade membrane where the NW metal contact is locally heated by Joule heating [2]. We demonstrate a real-time observation of the metal diffusion in the semiconducting NW using both Cu and Al metals.

We show characterization of the formed phase at atomic length scales with different (S)TEM techniques (electron diffraction tomography, energy dispersive X-ray spectroscopy (EDX) and HR(S)TEM) to understand how the metal atoms diffuse and incorporate into the germanide phase at the reaction front.

The location of the reaction interface is studied as a function of time, and interpreted using a diffusion model. In the case of Cu diffusion, surface diffusion of Cu along the formed segment is the rate limiting step at temperatures below 600°C. In the case of Al, self-diffusion of Al through the NW volume is the rate limiting step at temperatures below 400°C.

Model based EDX analysis shows that core shell structures are formed in both systems. In the case of Cu, a core of Cu₃Ge is found with thin shells of Cu, Ge and GeO₂, respectively.

In the case of Al, a core of pure Al is formed with thin shells of Ge, Al₂O₃ and a Ge containing region of Al₂O₃, respectively. These findings combined with the diffusion model support the hypothesis for Cu surface diffusion, and show that in both systems Ge surface diffusion takes place from the reaction interface to the metal reservoir, without noticeably influencing the reaction speed.

[1] <http://denssolutions.com/products/nano-chip>

[2] M. Mongillo, P. Spathis, G. Katsaros, P. Gentile, M. Sanquer and S. De Franceschi, ACS Nano, **5**, 7117-7123 (2011).

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