One-Dimensional Heterostructures Fabricated in InAs/InP Nanowhiskers

Previously, researchers have grown one-dimensional semiconductor nanowhiskers and then made diodes and bipolar transistors *between* crossed, differently doped whiskers. However, researchers from the Solid-State Physics/Nanometer Consortium at Sweden's Lund University have fabricated a heterostructure device *within* a single 40-nm-diameter InAs whisker. They used size-selected Au aerosol seed particles along with chemical-beam epitaxy (CBE) to sprout their nanowhiskers from GaAs substrates. These tiny InAs pillars contain either one or a sequence of InP barriers, ranging from 1.5 nm to 100 nm thick, and boast atomically sharp interfaces between the layers.

After depositing the Au seed particles into (111)B GaAs substrates, M.T. Björk and colleagues used CBE to grow the long whiskers at 420°C. The beam pressures were 0.3 mbar for the trimethyl indium (TMIn) source, 2.0 mbar for the tertiary butyl arsine source, and 3.0 mbar for the tertiary butyl phosphine source. The alternating InAs and InP layers were then grown by switching between the two Group V sources while the TMIn source was extinguished. As reported in the February 4 issue of *Applied Physics Letters*, the researchers found that the thicknesses were highly reproducible, and transmission electron microscopy (TEM) images showed that growth can occur in the ⟨001⟩ direction as well as in the more commonly reported ⟨111⟩B direction.

The low growth rate (about 1 monolayer per second) and high vapor pressures of the Group V sources is responsible for the monolayer abruptness of the interfaces as imaged by high-resolution TEM, according to the researchers.

The researchers report that measurements of thermionic emission across an InP heterobarrier are most telling. They demonstrated that the thermally excited currents follow the expected Arrhenius relation and deduced an InP barrier height (0.6 eV) that is very close to the bulk value. This result is gratifying, said the researchers, as it shows that the whiskers' tiny cross sections permit efficient lateral relaxation of the two materials. This allows a combination of materials with dissimilar lattice constants that is not possible with ordinary epitaxy on a larger scale, due to, for example, the incorporation of misfit dislocations once the critical thickness of several monolayers is exceeded.

The researchers also proposed new branches of physics phenomena and new families of device structures that can be realized with these semiconductor nanowhiskers.

"These results open the possibility of realizing novel 1-D systems, such as heterostructures integrated in scanning probe or field-emission tips, 1D–0D–1D resonant tunneling devices, and one-dimensional superlattice arrays of intercoupled quantum dots," said Björk, "and devices for quantum optics and photonics applications."

RICHARD N. LOUIE

Intermittency of CdSe Quantum-Dot Photon Emissions Follows a Power Law Distribution

The development of sources that emit single photons separated in time is essential to the success of quantum optics applications such as quantum cryptography. This time-separated emission phenomenon is called "antibunching," since none of the emissions occurs simultaneously; emission of two or more photons simultaneously is called "bunching." Antibunching has been achieved over short time intervals through fluorescence of atoms, molecules, quantum dots (QDs), and single nitrogen vacancy centers in crystals as well as electroluminescence from QDs in *p-i-n* junctions. But over longer time periods, these same systems tend to turn on and off at irregular intervals, a phenomenon known as "intermittency." By studying the emission behavior of CdSe quantum dots over an unprecedented time scale (from nanoseconds to tens of seconds), researchers at the Ecole Normale Supérieure et Université Pierre et Marie Curie in Paris have found that intermittency follows a power law, instead of the normal exponential decay seen in two-state systems with constant on/off rates.

As reported in the December 1, 2001, issue of *Optics Letters*, CdSe quantum dots of 1.8-nm radius were deposited on a glass coverslip by spin coating a nanomolar solution of QDs in butanol and a thin film of poly methyl (methacrylate). These QDs were then excited by the 514-nm line of an Ar^+ laser, and the fluorescence photons were detected by a 50/50 nonpolarizing beam splitter followed by two (start and stop) single-photon avalanche photodiodes. A picosecond time analyzer was used to measure delays between emission times of the photons. A histogram of coincidence counts versus photon time delay shows the characteristic dip at zero time delay that is the signature of antibunching systems. There is a separation between all photon emissions; no emissions are occurring at the same time (time delay = 0).

The researchers used the normalized autocorrelation function (ACF) to analyze the emission properties over time scales ranging from 100 ns up to 1000 s. From 100 ns up to 100 μs, the ACF is nearly constant, indicating no intermittency—complete antibunching is observed. After 100 μs, the ACF slowly decreases before dropping off abruptly as the time approaches the measurement duration. Increasingly longer on and off states occur as the measurement duration increases. This behavior cannot be explained by exponential decay equations used to describe two-state (on and off) systems. Rather, a power law dependence is necessary to model the densities of probability of on and off states.

The researchers caution that because of this power-law dependence, QDs cannot be considered stationary systems at long time scales, so conventional ACF analysis should be used with care.

TIM PALUCKA

3D Nanoarray Microporous Carbon Structure Achieves High Surface Area

Microporous carbon has become of great interest in recent years due to its ability to store natural gas and act as the electrodes of an electric double-layer capacitor. As reported in the December 17, 2001 issue of *Chemistry of Materials*, researchers from Tohoku University were able to synthesize a three-dimensional (3D) nano-array microporous carbon structure, achieving a [Brunner–Emmet–Teller (BET) method] surface area as high as 3600 m^2/g, using zeolite Y as the template.

The researchers used a three-step method to fill carbon into the nanochannels of zeolite Y. They heated the zeolite/poly(furfuryl alcohol) (PFA) composite to 700°C in N_2 and then used chemical vapor deposition of propylene to introduce carbon. They then heat-treated the composite at 900°C under N_2 flow.

The x-ray diffraction pattern revealed that carbons liberated from the zeolite framework showed intense peaks with highly ordered parts and periodicity of about 1.4 nm, corresponding to the spacing of the {111} plane of zeolite Y. High-resolution transmission electron microscopy (HRTEM) showed the microporous carbon with excellent 3D ordering and periodicity of about 1.3 nm. HRTEM also showed no signs of stacking structure of graphene sheets or any single layers inside carbon–carbon particles.

Another noticeable characteristic of the synthesized carbon was its high surface area from N_2 adsorption, said the researchers. They were able to achieve a high surface area without the usual chemical activation using KOH, reducing the presence of mesoporosity and the size of pore

https://doi.org/10.1557/mrs2002.31 Published online by Cambridge University Press