within oxide nanotubes heretofore has not. Researchers from Y. Bando's group at the National Institute for Materials Science, Ibaraki, Japan, have synthesized single-crystalline MgO nanotubes and demonstrated that such a structure filled with Ga serves as a nanothermometer with a very wide temperature range. The synthesis of the nanotubes and *in situ* Ga filling was accomplished using a one-step process.

As reported in the August 4 issue of *Applied Physics Letters*, National Institute for Materials Science researcher Y.B. Li and co-workers used $Ga_2O_3$ and Mg powders in a vertical induction furnace to obtain *in situ*-filled oxide nanotubes. With the $Ga_2O_3$ placed in the high-temperature (1300–1400°C) zone and the Mg placed in a lower-temperature (800–900°C) zone, a white powder was collected from the surface of a graphite inductor, used as a heating element, located near the Mg. An x-ray diffraction pattern shows that the product is composed of only two crystal phases: cubic MgO and orthorhombic Ga. The researchers performed a chemical composition analysis by means of an energy-dispersion spectrometer attached to a transmission electron microscope to confirm that the nanotubes are composed of Mg and O in an atomic ratio of 1:1.

In addition to verifying that the nanostructures are Ga-filled MgO nanotubes, transmission electron micrographs (TEMs) show that the nanotubes are several micrometers long, have an outer dimension of ~30–100 nm, and have a uniform inner dimension ranging from 20 nm to 60 nm. Most nanotubes are closed at both ends but are not entirely filled with Ga. In one frequently observed morphology, a continuous column of Ga fills the nanotube except for a short section near one tip; in another, a central portion of the nanotube is left unfilled.

Unlike polycrystalline oxide nanotubes, the MgO nanotubes produced by Li and co-workers have square cross sections. A high-resolution TEM shows that the spacing between two neighboring parallel fringes both in the longitudinal and transverse direction is 2.10 Å, which is equal to the spacing between the [200] planes of cubic MgO. The researchers deduced that the nanotubes' growth direction, and therefore the nanotube axis, is the [100] direction of cubic MgO.

The researchers used a heating holder in a transmission electron microscope to investigate the thermal expansion of liquid Ga columns inside MgO nanotubes. After plotting the distance between the tips of two Ga fragments within a MgO nanotube as a function of temperature and obtaining a linear relationship with no hysteresis, the researchers realized that they had fabricated a virtually perfect nanothermometer. The researchers said that carbon nanotubes degrade quickly in air as the temperature approaches 600–700°C, while MgO, by contrast, is an extremely temperature-stable refractory compound. The researchers calibrated one particular nanothermometer by expressing the temperature as a function of two independent parameters—the total length of the column of Ga in the nanotube and the distance between two fragments of Ga at some reference temperature. Although the ultimate range of the nanothermometer is limited only by the melting and boiling points of Ga (about 30°C and 2205°C, respectively) the two parameters determine the working temperature range; for a typical Ga-filled MgO nanotube, it is about 30–800°C.

Li and co-workers said that MgO nanotubes filled with In were prepared by a similar process whereby $In_2O_3$ powder was substituted for $Ga_2O_3$ powder. They therefore believe that their method may be universal for preparing metal-filled oxide nanotubes.

STEVEN TROHALAKI

## 100-Fold X-Ray Source Brightness Improvement Possible with Liquid-Metal-Jet Anode

Compact electron-impact x-ray sources dominate diagnostics and imaging in medicine, industry, and science. Their key figure of merit, the source brightness, is proportional to the electron-beam power density at the anode. Higher brightness results in higher-resolution imaging. In this respect, the current industry standard—rotating anode and microfocus technologies—show little potential for further improvement due to their intrinsic thermal heat-transfer limitations. Recently, O. Hemberg and co-workers of the Hertz Group at the Royal Institute of Technology in Stockholm have developed an x-ray source based on a liquid-metal-jet-stream anode potentially allowing a more than 100-fold brightness increase for such devices, as reported in the August 18 issue of *Applied Physics Letters*.

The experimental system consisted of a liquid-metal-jet system with a high-pressure tank enclosed in an IR heater, a 75-µm ruby pinhole nozzle, and a sintered stainless-steel particle filter. The chosen Sn/Pb metal alloy was heated to 250°C and forced through the nozzle by applying pressure up to 200 bars, producing a laminar jet with a speed of up to 60 m/s. The electron beam was focused onto the liquid-metal jet to give a 150-µm full width at half maximum focal spot, exhibiting about 100 W power. The jet absorbed 42% of the electron beam, leading to a maximum x-ray brightness of $1.4 \times 10^{10}$ photons/($mm^2$ sr s eV) at the Sn $K_\alpha$ peak with an average electron-beam power density of 3 kW/$mm^2$. Boiling and evaporation were observed at very high electron-beam powers, relative to the jet speeds.

The ideal jet materials for this application are metals and alloys with a low melting point, due to their high electric conductivity, high thermal heat capacity, and high Z. In particular, the thermal heat capacity is crucial to achieve high-brightness operation. The selected material was a Sn/Pb solder with a melting point of 183°C, which combines favorable thermodynamic properties with a Sn x-ray line emission that is particularly suitable for mammography.

The unique feature of this anode technology is the possibility of tailoring the system to high-brightness operation, primarily because a stable liquid-metal jet has the potential to achieve a higher speed than a rotating anode, and its regenerative nature results in a higher thermal heat capacity and heat-transfer rate due to the achievable high mass throughput.

ALFRED A. ZINN

## AlGaAs Microcooler with 2°C Maximum Cooling at 100°C Demonstrated

Cooling of semiconductor laser diodes can enhance performance by reducing threshold currents, increasing power output, and enhancing spectral stability. Cooling can also boost GaAs integrated-circuit performance in power microwave and millimeter wave applications, since it lowers noise and increases gains. Integrated microcoolers are, in many cases, the most efficient approach to such cooling tasks. Conventional thermoelectric coolers such as $Bi_2Te_3$-based systems, however, are fundamentally incompatible with the most common semiconductor phases Si, GaAs, and InP, rendering them impractical for integrated applications. J. Zhang and N.G. Anderson at the University of Massachusetts, Amherst, and K.M. Lau at the Hong Kong University of Science & Technology have fabricated a stand-alone AlGaAs-based superlattice microcooler, which represents an important step toward monolithically integrated microcooler structures for GaAs-based microelectronic devices.

Even though Si, GaAs, and InP are not considered thermoelectric materials, recent investigations have shown that significant improvements of their thermoelectric figures of merit can be