a 980 nm laser diode show two main emission bands centered at 479 nm and 653 nm which correspond to the strong $^1G_4 \rightarrow {}^3H_6$ transition and weak $^1G_4 \rightarrow {}^3F_4$ transition, respectively. The γ-AlON: 1.2 mol% Yb, 0.5 mol% Tm samples reach the maximal upconversion intensity. Concentration quenching was observed for samples with larger concentrations of Tm^{3+}. The researchers said that the dependence of upconversion intensity on pumping power intensity demonstrates a two-photon process. Based on the energy matching conditions, the researchers concluded that two 980 nm photons are absorbed by Yb^{3+} to generate $^2F_{7/2} \rightarrow {}^2F_{5/2}$ transitions and then induce the excitation of Tm^{3+} from the ground $^3H_6$ level to the $^1G_4$ level by an energy transfer upconversion process. The researchers reported that the $^1G_4 \rightarrow {}^3H_6$ and $^1G_4 \rightarrow {}^3F_4$ transitions generate upconversion luminescence at around 479 nm and 653 nm, respectively.

ZHAOYONG SUN

AlInN Films Display Negative Imaginary Conductivity at Terahertz Frequencies

The optical conductivity of some semiconducting nanostructures has displayed negative imaginary conductivity at terahertz (THz) frequencies. This is believed to be due to confinement effects that cause a transient current reversal. T.-T. Kang, M. Yamamoto, M. Tanaka, A. Hashimoto, A. Yamamoto, R. Suto, A. Noda, D.W. Liu, and K. Yamamoto at the University of Fukui, Japan, have reported observation of the negative imaginary parts of complex conductivities in indium-rich films of AlInN using terahertz time-domain optical spectroscopy.

The researchers chose to study AlInN alloys which allowed them to adjust the energy bandgap by adjusting the alloy composition. These alloys are potential candidates for high-power THz applications that could be used in conjunction with the 1300–1550 nm laser sources used in fiber-based communications systems. They deposited 250 nm films of indium-rich alloys directly on C-plane sapphire using metalorganic chemical vapor deposition with no buffer layers that would complicate the analysis of the experiment. As reported in the August 15 issue of *Optics Letters* (DOI: 10.1364/OL.34.002507; p. 2507), the researchers tuned the bandgap of the indium-rich nitride films for use with 1.3–1.5 μm lasers, and reported on results of a film with an aluminum content of 20%. To probe the film's optical properties, the research group transmitted electromagnetic waves with frequencies from 200 GHz to 2 THz through the sapphire and the film. After some data processing to remove noise and taking a fast Fourier transform to find the frequency dependence of the response, they used the measured complex dielectric constant to find the complex conductivity.

The imaginary part of the conductivity of the film is slightly below zero at the lowest frequencies measured, and has a linear response with a negative slope up to 2 THz. The size of this effect is significant, with the imaginary part at 2 THz making up approximately a third of the real part. The researchers discuss the origins of the negative imaginary part of the conductivity in terms of the confinement of electrons due to the nanoscale dimensions of the samples, enhanced backscattering, and the compositional inhomogeneity of the AlInN alloy that enhances carrier localization in the film. Potential fluctuations produce the same confinement of the electrons that nanostructure edges do, causing similar backscattering that produces transient current reversal and a negative imaginary conductivity.

JIM RANTSCHLER

Graphene Nanoribbons Show High Current Capacity and Thermal Conductivity

The unique properties of graphene make it attractive for a wide range of potential electronic devices. R. Murali, Y. Yang, K. Brenner, T. Beck, and J.D. Meindl at the Georgia Institute of Technology have been studying graphene as a potential replacement for copper in on-chip interconnects in integrated circuits. They have now reported measurements of thermal conductivity and breakdown current density in narrow graphene nanoribbons in the June 15 issue of *Applied Physics Letters* (DOI: 10.1063/1.3147183; # 243114).

"Our measurements show that graphene nanoribbons have a current carrying capacity of more than 108 amps per square centimeter, while a handful of them exceed 109 amps per square centimeter," said Murali, a senior research engineer in Georgia Tech's Nanotechnology Research Center. "This makes them very robust in resisting electromigration and should greatly improve chip reliability."

Electromigration is a phenomenon that causes transport of material, especially at high current density. In on-chip interconnects, this eventually leads to a break in the wire, which results in chip failure.

"In addition to the high current carrying capacity, graphene nanoribbons also have excellent thermal conductivity," Murali said.

Because heat generation is a significant cause of device failure, the researchers also measured the ability of the graphene nanostructures to conduct heat away from devices. They found that graphene nanoribbons have a thermal conductivity of more than 1000 W/mK for structures <20 nm wide.

"This high thermal conductivity could allow graphene interconnects to also serve as heat spreaders in future generations of integrated circuits," said Murali.

To study the properties of graphene interconnects, Murali and co-workers began with flakes of multi-layered graphene removed from a graphite block and placed onto an oxidized silicon substrate. They used electron beam lithography to construct four electrode contacts, then used lithography to fabricate devices consisting of parallel nanoribbons of widths ranging between 16 nm and 52 nm and lengths of between 0.2 μm and 1 μm.

The breakdown current density of the nanoribbons was then studied by slowly applying an increasing amount of current to the electrodes on either side of the parallel nanoribbons. A drop in current flow demonstrated the breakdown of one or more of the nanoribbons.

In their study of 21 test devices, the researchers found that the breakdown current density of graphene nanoribbons has a reciprocal relationship to the resistivity.

Because graphene can be patterned using conventional chip-making processes, manufacturers could make the transition from copper to graphene without a drastic change in chip fabrication.

"Graphene has very good electrical properties," Murali said. "The data we have developed so far looks very promising for using this material as the basis for future on-chip interconnects." □

https://doi.org/10.1557/mrs2009.192 Published online by Cambridge University Press