already showed that chlorotoxin combined with nanoparticles dramatically slows tumors' spread. They will see whether that ability could extend to brain cancer, the most common solid tumor to affect children.

Merely improving imaging, however, would improve patient outcomes.

"Precise imaging of brain tumors is phenomenally important. We know that patient survival for brain tumors is directly related to the amount of tumor that you can resect," said Ellenbogen, professor and chair of neurological surgery at the UW School of Medicine. "This is the next generation of cancer imaging," he said. "The last generation was CT, this generation was MRI, and this is the next generation of advances."

LEGO Toy Serves as Model for Microfluidic Arrays

A research team led by J. Frechette and G. Drazer of Johns Hopkins Institute for NanoBio Technology has used LEGO pieces to re-create microscopic activity taking place inside lab-on-a-chip devices at a scale they can more easily observe. As reported in the August 14 issue of *Physical Review Letters* (DOI:10.1103/PhysRevLett.103.078301; #078301), the research team constructed a square array using cylindrical LEGO pegs stacked two high and arranged in rows and columns on a LEGO board to create a lattice of obstacles. The board was attached to a Plexiglas sheet to improve its stiffness and pressed up against one wall of a Plexiglas tank filled with glycerol. Stainless steel balls of three different sizes, as well as plastic balls, were manually released from the top of the array; their paths to the bottom were tracked and timed with a camera.

"Microfluidic arrays are like miniature chemical plants," said Frechette, an assistant professor of chemical and biomolecular engineering in the university's Whiting School of Engineering. "One of the key components of these devices is the ability to separate one type of constituent from another. We investigated a microfluidic separation method that we suspected would remain the same when you scale it up from micrometers or nanometers to something as large as the size of billiard balls."

Graduate students M. Balvin and T. Iracki, and undergraduate student E. Sohn, all from the Department of Chemical and Biomolecular Engineering, performed multiple trials using each type of bead. They progressively rotated the board, increasing the relative angle between gravity and the columns of the array (i.e., altering the forcing angle). In doing so, they saw that the large balls did not move through the array in a diffuse or random manner as their small counterparts usually did in a microfluidic array. Instead, their paths were deterministic, meaning that they could be predicted with precision, said Drazer, also an assistant professor in the Whiting School of Engineering.

The researchers also noticed that the path followed by the balls was periodic once the balls were in motion and coincided with the direction of the lattice. As the forcing angle increased, some of the balls tended to shift over one, two, three, or as many as four pegs before continuing their vertical fall.

"Our experiment shows that if you know one single parameter—a measure of the asymmetry in the motion of a particle around a single obstacle—you can predict the path that particles will follow in a microfluidic array at any forcing angle, simply by doing geometry," Drazer said.

The fact that the balls moved in the same direction inside the array for different forcing angles is referred to as phase locking. If the array were to be scaled down to micro- or nanosize, the researchers said they would expect these phenomena to still be present and even increase depending on the factors such as the unavoidable irregularities of particle size or surface roughness.

"There are forces present between a particle and an obstacle when they get really close to each other which are present whether the system is at the micro- or nanoscale or as large as the LEGO board," Frechette said. "In this separation method, the periodic arrangement of the obstacles allows the small effect of these forces to accumulate, and amplify, which we suspect is the mechanism for particle separation."

This principle could be applied to the design of micro- or nanofluidic arrays, she said, so that they could be fabricated to "sort particles that had a different roughness, different charge, or different size. They should follow a different path in an array and could be collected separately."

Phase locking is likely to become less important, Drazer said, as the number of particles in solution becomes more concentrated.

"Next," he said, "we have to look at how concentrated your suspension can be before this principle is destroyed by particle-particle interactions."

Upconversion Luminescence Found in Yb^{3+}, Tm^{3+}-Codoped γ-AlON Phosphors

Aluminum oxynitride (AlON) has been found to be a suitable phosphor matrix. Stokes luminescence properties of metal-ion–doped AlON have been studied recently. However, up to now, upconversion luminescence in an AlON phosphor has not been reported. Now, F. Zhang, L. An, X. Liu, G. Zhou, X. Yuan, and S. Wang at the Shanghai Institute of Ceramics of the Chinese Academy of Sciences have found that Yb^{3+}, Tm^{3+}-codoped AlON shows strong upconversion luminescence at optimal concentrations of Yb^{3+} and Tm^{3+}. The upconversion emission mechanism was also investigated.

As reported in the August issue of the *Journal of the American Ceramics Society* (DOI: 10.1111/j.1551-2916.2009.03131.x; p. 1888), Zhang and co-workers prepared γ-AlON matrix first by carbothermal reduction and nitridation processing using high purity Al_2O_3 and carbon black as precursors. Next, a series of Yb^{3+}, Tm^{3+}-codoped γ-AlON powders with 0.3–1.2 mol% Yb^{3+} and 0.4–0.6 mol% Tm^{3+} were prepared by conventional solid-state reaction method using high purity Yb_2O_3, Tm_2O_3, and as-synthesized γ-AlON mixture.

After the preparation, the researchers conducted structure characterization, absorption spectroscopy, and upconversion luminescence spectroscopy of these samples at room temperature. The absorption spectrum of the γ-AlON: Yb, Tm phosphor exhibits the typical optical transitions of both Tm^{3+} and Yb^{3+} which are $^3H_6 \rightarrow {}^3F_4$, $^3H_5$, $^3H_4$, $^3F_{2,3}$, and $^1G_4$ for Tm^{3+} and $^2F_{7/2} \rightarrow {}^2F_{5/2}$ for Yb^{3+}. The intense absorption band at ~980 nm of Yb^{3+} associated with the transition $^2F_{7/2} \rightarrow {}^2F_{5/2}$ demonstrates that a 980 nm laser can efficiently excite the Yb^{3+}, Tm^{3+}-codoped phosphors. Upconversion luminescence spectra of all samples excited by 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." □