Rare-earth Information Center

Insight

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Electrorheological (ER) Fluids

Electrorheological (ER) fluids have electrically controllable stiffness, viscosity, and heat transfer properties. ER fluids are viewed as candidate materials for use in viscous clutches, shock absorbers, and other applications where variable coupling is required. An ER fluid consists of a suspension of fine polarizable particles in a liquid of low dielectric constant. The density of the particles is closely matched to that of the fluid to ensure good dispersion. When an electric field is applied to the fluid, the particles are polarized and organized into chains. As the electric field is increased, the polarization is increased and the chains pull together and lengthen, resulting in a higher fluid viscosity and stiffness. Amusingly, melted chocolate is made up of solid droplets in an oily fluid and can be changed to a solid by the application of an electric field. Of more practical interest is a recent paper by J. Yin and X. Zhao {*J. Phys. D: Appl. Phys.*, **34**, 2063-7 (2001) on the effects of rare earth doping on the electrorheological properties of fluids based on TiO_2 doped with Ce in dimethylsilicone oil. TiO_2 is desirable because of its high dielectric constant and because it forms good chain structures when an electric field is applied, but it has poor shear stress characteristics. This is believed to be due to the low electrical conductivity of TiO_2. The Ce doped TiO_2 was prepared by sol-gel processing and exhibits a sheer stress that is five to six times higher that pure TiO_2, and in addition has a significantly broader operational temperature range. The enhanced behavior is associated with increases in dielectric constant, loss tangent, and conductivity, which also increase with temperature in the doped material, but are temperature independent in the pure TiO_2 materials.

Amorphous Ceramic $Al_{32.4}Er_{7.6}O_{60}$ Fiber

Fiber reinforced composites are extremely common, but the majority of them rely on a polymer matrix and are not suitable for high temperature applications. There is considerable interest in fiber reinforcing of monolithic ceramics and metals, but currently such composites are restricted to simple shapes since they cannot be deformed once they have been cast. If the reinforcing fiber underwent viscous flow deformation rather than brittle fracture, the preparation of complex shapes would be greatly simplified. Recently, Y. Waku et al. {*J. Mater. Sci.*, **36**, 2435-40 (2001)} have reported on an amorphous ceramic fiber made by melt extraction from a melt at the $Al_2O_3 - Er_2O_3$ eutectic composition. In melt extraction, the tapered (v-shaped) edge of a rotating wheel is dipped into a molten puddle, and the fiber is pulled from the melt. Waku et al. produced a 20 μm amorphous fiber in this fashion. The amorphous fiber has a Young's modulus over twice that of conventional glass fibers and maintains its strength up to 1100 K, while the glass fiber has only 30% of its room temperature strength at 1023 K. At a temperature of 1273 K, the fibers show large viscous flow deformation. At slightly higher temperatures, a nanocomposite of a crystalline phase in an amorphous matrix is formed. The room temperature Young's modulus of this nanocomposite is about 235 GPa compared to 165 GPa for the amorphous fiber.

Self-assembled Rare-earth Silicide Nanowires

Despite the fact that lithographic techniques are capable of producing ever-finer features, there is always someone who wants something smaller.

Self-assembly is a means to produce extremely fine nanowires. Conceptually, the idea is rather simple. Start with a single crystal substrate, in this case Si(001), which is readily available. Next, deposit a partial monolayer of your element or compound of choice, rare earth silicides for example. If the deposited layer is tetragonal and chosen so that the a-axis is a good lattice match to the Si(100), there will be little strain along the a direction. If the film is grown so that the c-axis lies in the plain of the film, the c-axis will have a significant lattice mismatch with the substrate so that it is energetically favorable to grow in the a direction. At low coverages, this results in long nanowires running parallel to the crystal axis of the substrate. As the coverage is increased, more and more of these wires intersect, and a nanogrid is formed. J. Nogami et al. {*Phys. Rev. B*, **63**, 23305 (2001)} have demonstrated that the rare-earth silicides will form nanowires, nanometers wide and hundreds of nanometers long. The wires were characterized by scanning tunneling microscopy and scanning tunneling spectroscopy and found to be metallic.

Rare earth Oxide Dielectric FET's

As has been discussed in previous issues of the *Insight*, in order to downscale complimentary metal-oxide-semiconductor (CMOS) technology below the 100-nm-gate-length generation requires the replacement of the SiO_2 gate dielectric, since this size will require SiO_2 layers less than 10-15 Å. At this thickness, the leakage through SiO_2 layers becomes unacceptable. Of course, compatibility with CMOS technology is required. Two recent papers report the fabrication of field-effect transistors with RE_2O_3 dielectric layers. L. A. Ragnarsson et al. {*Appl. Phys. Lett.*, **78**, [26], 4169-71 (2001)} used molecular beam-deposited Y_2O_3 in an *n*-channel MOSFET. Charge mobility in the device was found to be limited by interface states and fixed charge. J. W. Johnson et al. {*J. Electrochem. Soc.*, **148**, [6], G303-G306 (2001)} fabricated $SiO_2/Gd_2O_3/GaN$ MOSFETs where molecular beam epitaxy was also used to deposit the RE_2O_3 layer. The device also operated in the *n*-channel mode. The devices were characterized by high drain breakdown voltages and low gate leakage.

Along similar lines, S. Stemmer et al. {*Appl. Phys. Lett.*, **79**, [1], 102-4 (2001)} have reported on the structure and stability of La_2O_3/SiO_2 layers on Si(001). The La_2O_3 films were deposited on standard ~ 2 nm thermal oxide grown on a doped p-type Si wafer. The La was reactively evaporated from a high temperature effusion cell in an oxygen molecular beam epitaxy system in the presence of molecular oxygen. It appears that the process is very similar to that in the two papers discussed above. The as deposited La_2O_3 was amorphous and remained so after rapid thermal annealing at 600°C in nitrogen. At 800°C, the material was crystallized, there was some diffusion of La into the Si, and the SiO_2 layer had increased in thickness. These later effects are not desirable and point up the difficulty in controlling SiO_2 formation when growing alternate dielectric layers.

Company Notes:

Less Common Metals Ltd. (LCM) of Great Britain has received The Queen's Award for International Trade in 2001. The award, which recognizes companies that have had significant success in the field of international trade, is given to only a handful of companies each year. LCM manufactures specialized rare earth alloys and is wholly owned by the Meldform Metals Group.

Sincerely,

R. W. McCallum
Director of RIC