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MAKING FLEXIBLE NANOTUBE ELECTRONICS

Developers at Nanomix Inc. (Emeryville, CA) are demonstrating that there is more than one way to achieve flexible electronics by putting nanotechnology concepts to work. Last week (*Nanotech Alert*, Sept. 19, 2003), we told you about interesting developments in the field of thin-film transistors by Nanosys (Medford, MA), which promises to make flexible circuitry much more practical. Nanomix takes a different approach, applying nanotube network transistors to polymer supports.
The Nanomix networks can be bent through angles of at least 60 degrees without any change in electronic properties, say researchers Jean-Christophe Gabriel, Keith Bradley and George Grüner in a brief paper in *Nano Letters,* web-released on September 9 2003. (Gruener, Nanomix's principal scientific advisor, is on leave from the physics department of UCLA.) The work is a potential challenge to a currently favored type of flexible electronics, based on organic light emitting diodes (OLEDs) and used for concepts such as flexible displays and 'electronic paper.' OLEDs are being pursued by a number of major companies and research consortia (including DuPont, Kodak, etc.), but suffer the disadvantage of low speed, due to low mobility of charge carriers in the organic molecules developed to date, such as poly(3-hexylthiophene). Common silicon or carbon nanotubes outperform them by three orders of magnitude, and are more suitable where you want to develop flexible electronics with computing power, rather than mere

displays. Nanotubes offer the additional advantage of being flexible and strong. During the past year, transistors made from sparse networks of carbon nanotubes, on rigid substrates, have showed good mobility and an on-off ration of at least 10^4. Nanomix has now figured out how to transfer these networks to flexible polymer substrates.
They grow the networks by chemical vapor deposition of 200-nm Si oxide films on Si substrates. The networks are randomly oriented rather than bundles of tubes. Metal contacts are patterned on to the networks (3.5 nm of Ti followed by 50 nm of Au, arranged as 200 micrometer pads separated by 50 micrometer gaps). They then attach them to flexible films, and lift off the networks; it's done by spin-coating a 15 micrometer film of polyimide (HMD 2610) on the assembly, curing, and dissolving the silicon in HF. The networks act as p-type field-effect transistors, but can be modified by chemically doping to make n-type field effect transistors (FETs) as well. When bent, the conductance of the networks drops, but reversibly recovers when the polymer substrate is straightened. The developers suggest that metallic conducting of networks could also be made using the process, simply by increasing the nanotube density.
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