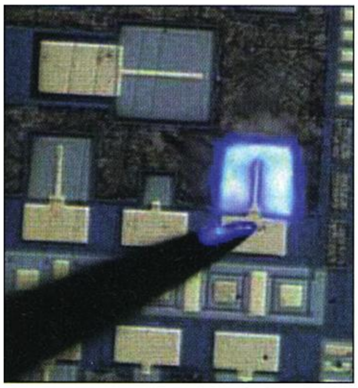
OPTOELECTRONICS

Blue Semiconductors Settle on Silicon

Researchers trying to coax light from semiconductors have a case of the blues, but they couldn't be happier. For the past several years they've managed to cajole semiconductor devices containing gallium nitride to emit blue light when pumped with electricity. That has opened a world of possible applications, including converting some of that blue light to other colors and combining them to make a chip-sized replacement for the light bulb. But blue semiconductor lights are still too expensive for such uses, in part because they're grown on expensive substrates such as sapphire. Now a team of U.S. researchers reports progress on a cheaper alternative.

In the 17 January issue of *Applied Physics Letters*, Asif Khan and colleagues at the University of South Carolina, Columbia, along with co-workers at Wright Patterson Air Force Base in Ohio and Sensor Electronic Technology Inc. in Troy, New York, describe a scheme for producing blue and green light-emitting diodes (LEDs) on a base of silicon, the cheap and ubiquitous substrate for microelectronics. They've also managed to make small LEDs just where they want them on the chip, an important step toward complex displays made up of thousands of separately controlled lighting elements. The new LEDs atop silicon aren't yet as bright as those grown on sapphire. Still, "it's a good development," says Fred Schubert, an electrical engineer at Boston University in Massachusetts. "Silicon substrates are cheap and big. So if a silicon LED technology succeeds, it would mean the technology could be very cheap."



Cheaper blue. Semiconductor light may one day replace the light bulb.

The garden-variety light bulb, little changed over the last century, costs just pennies to produce but is expensive to run. It pushes electricity through a tungsten filament, turning it white hot and producing 15 lumens/watt of soft white light and a lot of waste heat. Newer compact fluorescents, which excite gases to emit light, do better, turning out 60 lumens/watt. But LEDs, which inject energetic electrons into a solid semiconductor, have the potential to put them all in the shade. As these charges move through, they shed some of their excess energy as photons of light, the color of which depends on the exact combination of materials used in the device. And because this process generates far less heat, it can theoretically produce 250 lumens/watt, says Schubert.

But so far reality has fallen far short of theory. Billions of tiny cracks and other defects form in the gallium nitride as it is grown, and they resist the flow of electrical charges through the device, generating heat instead of light. To minimize the number of cracks, researchers grow their gallium nitride devices atop sapphire in part because it has a roughly similar crystal structure, making it easier for the gallium nitride to form an orderly lattice. Silicon's lattice is slightly different, and it suffers from other drawbacks as well. Most notably, at the temperatures usually used to vaporize gallium nitride and deposit it on the substrate—around 1000°C—silicon atoms evaporate off and get mixed up in the gallium nitride lattice, causing more defects that mar its optical properties.

Still, the lure of silicon's low cost has kept researchers searching for a way to make blue LEDs work. In 1998, an IBM team made some initial progress using a growth technique known as molecular beam epitaxy that works at a relatively cool 750°C. This produced LEDs that turned out ultraviolet and violet light, albeit about 1/15th the brightness achieved by devices grown on sapphire. Researchers from the New Jersey–based Emcore Corp. improved matters last September by using a technique known as metal-organic chemical vapor deposition to lay down a 20-nanometer-thick layer of buffering material on the silicon substrate and then grow the gallium nitride on top.

Khan and his colleagues combined the two approaches. First, they used a 700°C epitaxy technique to lay down a buffer layer of aluminum nitride. They then raised the temperature to 900°C and used vapor deposition to create gallium nitride. They also went beyond the other teams and used the masks and etching of conventional photolithography to place the gallium nitride only where they wanted it. The result was an array of tiny blue LEDs.

The new LEDs still only put out about one-fifth the light of those grown on sapphire. But Khan and others say they have other ideas up their sleeve to improve efficiency. The patterning technique also opens up the possibility of making full-color gallium nitride LED displays. Khan says that his team

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ScienceScope

No Holds Barred Researchers are planning to debate a controversial theory on the origin of AIDS. The United Kingdom's Royal Society will host a meeting in London in May to explore the contentious idea that HIV entered humans through a contaminated polio vaccine tested in Africa in the 1950s. The thesis, which received a flurry of attention in 1992 following an article in *Rolling Stone*, last year became a hot topic again when British journalist Edward Hooper published *The River*, a weighty tome on the subject.

The meeting, proposed by Simon Wain-Hobson, an AIDS researcher at the Pasteur Institute in Paris, will examine the notion that HIV or one of its simian cousins infected the primate cells used to manufacture an oral polio vaccine developed by Hilary Koprowski, then head of the Philadelphia-based Wistar Institute. An independent scientific panel convened by Wistar concluded in 1992 that there was an "extremely low" probability that the theory was correct, but Hooper and other critics say the panel failed to make a convincing case.

Wain-Hobson hopes that if Hooper, Koprowski, and other key players agree to attend the meeting, they can clarify the scientific issues. "Discussion is better than a year's worth of invective delivered at arm's length," Wain-Hobson says.

Can't Stand the Heat? Eager to avoid another failure, a suddenly timid NASA has delayed the launch of a science satellite pending further tests. The High Energy Transient Explorer 2 (HETE-2), the first spacecraft dedicated to the study of powerful gamma ray bursts, was ready for a 28 January lift-off from Kwajalein Atoll in the Marshall Islands. But last week NASA brass halted the countdown so that technicians could make sure the $8.5 million satellite is ready to withstand launch vibrations and the frigid cold of space.

The delay "came as a complete surprise," says HETE-2 investigator Kevin Hurley of the University of California, Berkeley, who worries that engineers might inadvertently create new problems when taking apart the craft for tests. But NASA's Don Savage says it was only prudent "to look over everything" given the agency's recent string of losses, including two high-profile Mars probes. If all goes well, HETE-2 should be bound for space by mid-May.

Contributors: Jon Cohen and Govert Schilling

has already managed to make green LEDs simply by adding a little indium to the gallium nitride mix. If the South Carolina team or their competitors can figure out a way to also get red gallium nitride LEDs, it would allow them to integrate both the light emitters and the electronics needed to drive them on the same silicon substrate, which would drastically drop their cost to produce. That promise is enough to keep the lights burning late into the night at semiconductor labs around the globe.

–ROBERT F. SERVICE

GEOLOGY

Discovering the Original Emerald Cities

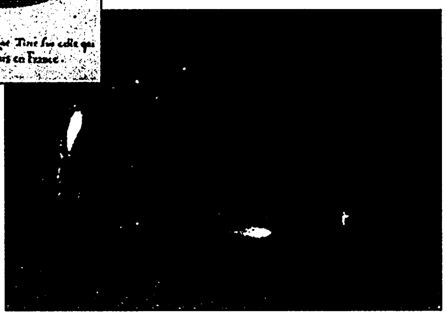
Emeralds have turned many an eye green with envy. The ancient Egyptians forced slaves to dig for the precious stones, prized as a symbol of immortality. Centuries later, Romans dominated the trade, setting the gems in gold jewelry. And when conquistadors in the 16th century captured mines in Colombia, they shipped back chests full of eye-popping emeralds that were snapped up by royalty, from Indian maharaji to Turkish sultans. Even today, dealers have no trouble spotting the exceptional clarity and intense color of the Colombian gems. But it's been notoriously difficult to track down the birthplaces of the murkier Old World emeralds.

Now on page 631, scientists describe a kind of atomic birth certificate that can peg where emeralds were grubbed from the ground. The technique might help dealers authenticate top-quality stones, and it could clear up the mysterious origins of Old World emeralds, including some famous gems. This new kind of detective work "is just the beginning," says Dietmar Schwarz, a mineralogist with Gübelin Gemmological Laboratory in Lucerne, Switzerland. Indeed, the approach is already providing information on ancient trade routes, and it might someday offer tantalizing hints of long-lost mines.

Emeralds are a kind of beryl, a mineral made when molten granite thrusts up into Earth's crust, cools, and hardens. Normally drab white or pale green, beryl can acquire a striking verdancy if the granite first muscles through rocks bearing chromium and vanadium. Hot water soaks up these and other elements, then crystallizes. Almost all the world's emerald deposits were formed this way.

Except in Colombia. There, hundreds of millions of years ago, black shale containing traces of chromium and vanadium washed off the west coast of South America. As the Caribbean Plate pushed eastward against the Brazilian Plate, it shoved the shale-covered sea floor onto the continent and twice created faults in the shale: first 65 million years ago, then again 38 million years ago. The squeezing and folding acted like a giant squeegee, forcing hot water into the black shales where the fluids picked up chromium, vanadium, and other ingredients of emerald. This brew percolated beneath impermeable shale layers until the pressure grew so great it ripped apart the rocks. The solution shot into the cracks, cooled, and gave birth to clear, blue-green emeralds, according to a scenario developed since the mid-1990s. But as researchers reconstructed this geologic history, they discovered more than a recipe for radiance: Colombian emeralds, it turns out, have unique oxygen isotope ratios that depend on where the stones were mined. So did emeralds from many mines elsewhere in the world.

Intrigued, Gaston Giuliani of the Petrographical and Geochemical Research Center (CRPG)-CNRS in Vandoeuvre-lès-Nancy, France—along with CRPG colleague Marc Chaussidon and Didier Giard and Daniel Piat of the French Association of Gemology—decided to see if they could use this isotopic tag to trace the origins of emeralds in artifacts. First they had to persuade the relics' wardens that they would do no harm. "No one wants you to touch [a precious specimen], no scratching,



Crown jewel. The first isotopic analysis of this 13th century French crown suggests that its central emerald came from Austria—more than 500 years before the mine's documented discovery.

nothing," says Fred Ward, an independent gemologist in Bethesda, Maryland, and author of the book *Emeralds*. But the French group wasn't intending to hack off a piece. To measure oxygen isotopes, the researchers fire a beam of cesium atoms at the emerald, vaporizing a few atoms and leaving a hole a mere 20 micrometers wide and a few angstroms deep.

Reassured that samples weren't visibly marred in a test run, Henri-Jean Schubnel, the director of the National Museum of Natural History in Paris, and curators elsewhere let the team have a crack at a handful of gems spanning the history of emerald trading—from a Gallo-Roman earring to a thumb-sized emerald set on the Holy Crown of France to treasure from a Spanish galleon. "Gems with this pedigree are jealously guarded by museums, so to get access is quite an accomplishment," says Terri Ottaway, a geochemist and gemologist with the Royal Ontario Museum in Toronto, who has worked on Colombian emeralds. As expected, the emeralds from the wrecked galleon bore the isotopic signature of Colombian mines. But surprisingly, the stone in the earring turned out to come from the Swat River in Pakistan, demonstrating that the Romans had access to gems from much farther afield than Egypt. And the 13th century French crown, it turns out, is graced by an emerald from the Austrian alps—one that appears to have been unearthed more than 500 years before the first known description of these deposits.

For gem dealers, isotopes may help tell Colombian emeralds from top Afghani stones, which sometimes resemble each other, says Schwarz, who's working with Giuliani's team to see if oxygen isotopes can pinpoint the origins of rubies and sapphires. Customers care about an emerald's source, Schwarz says, because it helps determine value. Isotopes could also provide an additional tool for spotting synthetic emeralds, which are hard to distinguish from flawless gems. "We have big-time problems with fraud," says Ward.

The technique may offer an important new tool for archaeologists, too. They have a hard time tracing stony emeralds, the opacity of which tends to obscure microscopic drops of fluid or other telltale inclusions of a source region. Oxygen isotopes may lift this veil. "It's a great idea," says Ottaway, "but I'd like to see it tested with more samples." And who knows: If some ancient emerald turns out to be an isotopic orphan, it may point the way to a mine not found on any map.

–ERIK STOKSTAD

CELL BIOLOGY

Generating New Yeast Prions

For a controversy that many insist is settled, the long-running argument over whether abnormal proteins called prions act alone to cause disease has had amazing staying power. The stakes in the debate are high, because prions are implicated in several fatal neurodegenerative diseases, including human Creutzfeldt-Jakob disease and bovine spongiform encephalopathy, or "mad cow disease." But while most researchers now

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