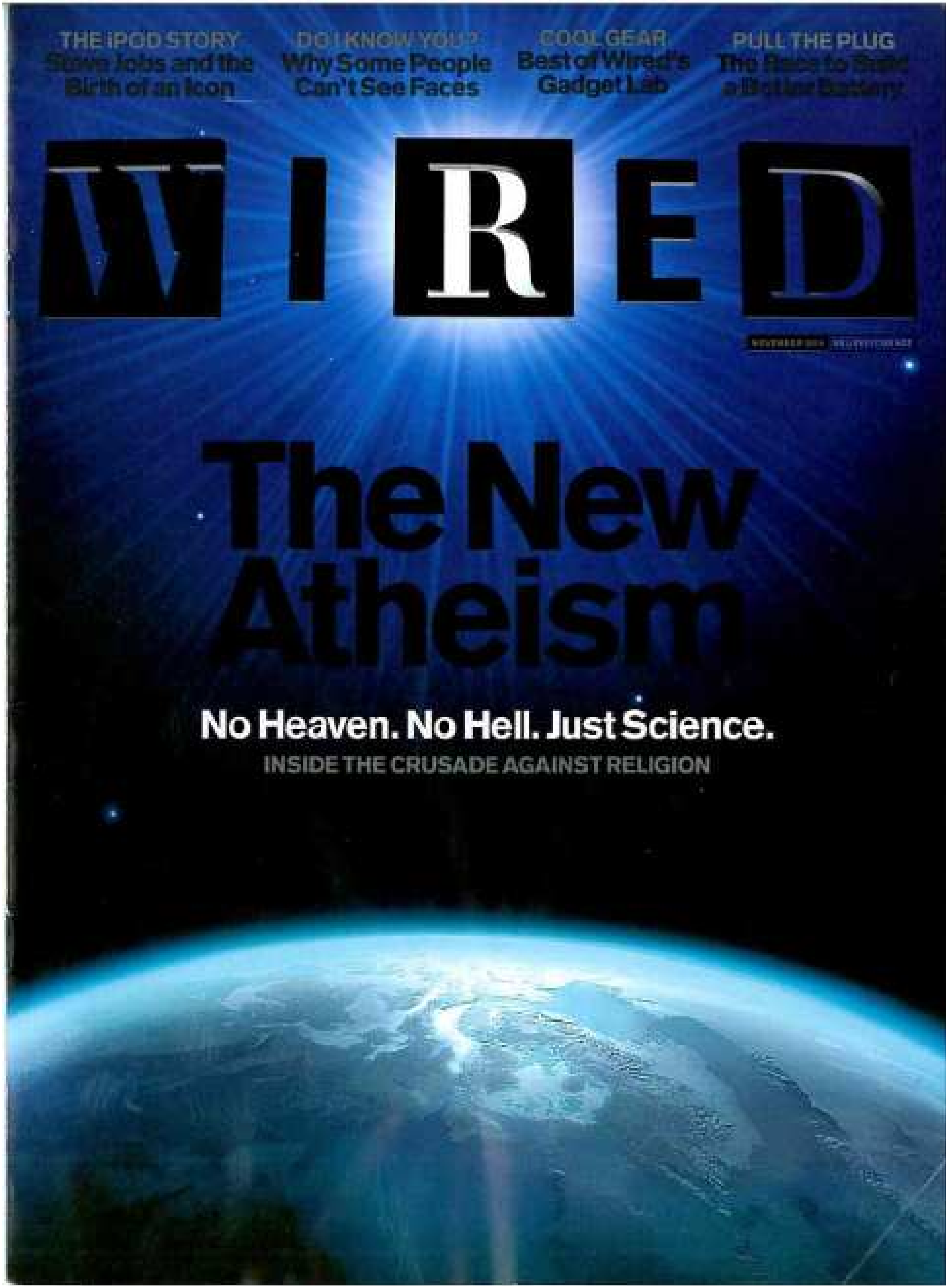
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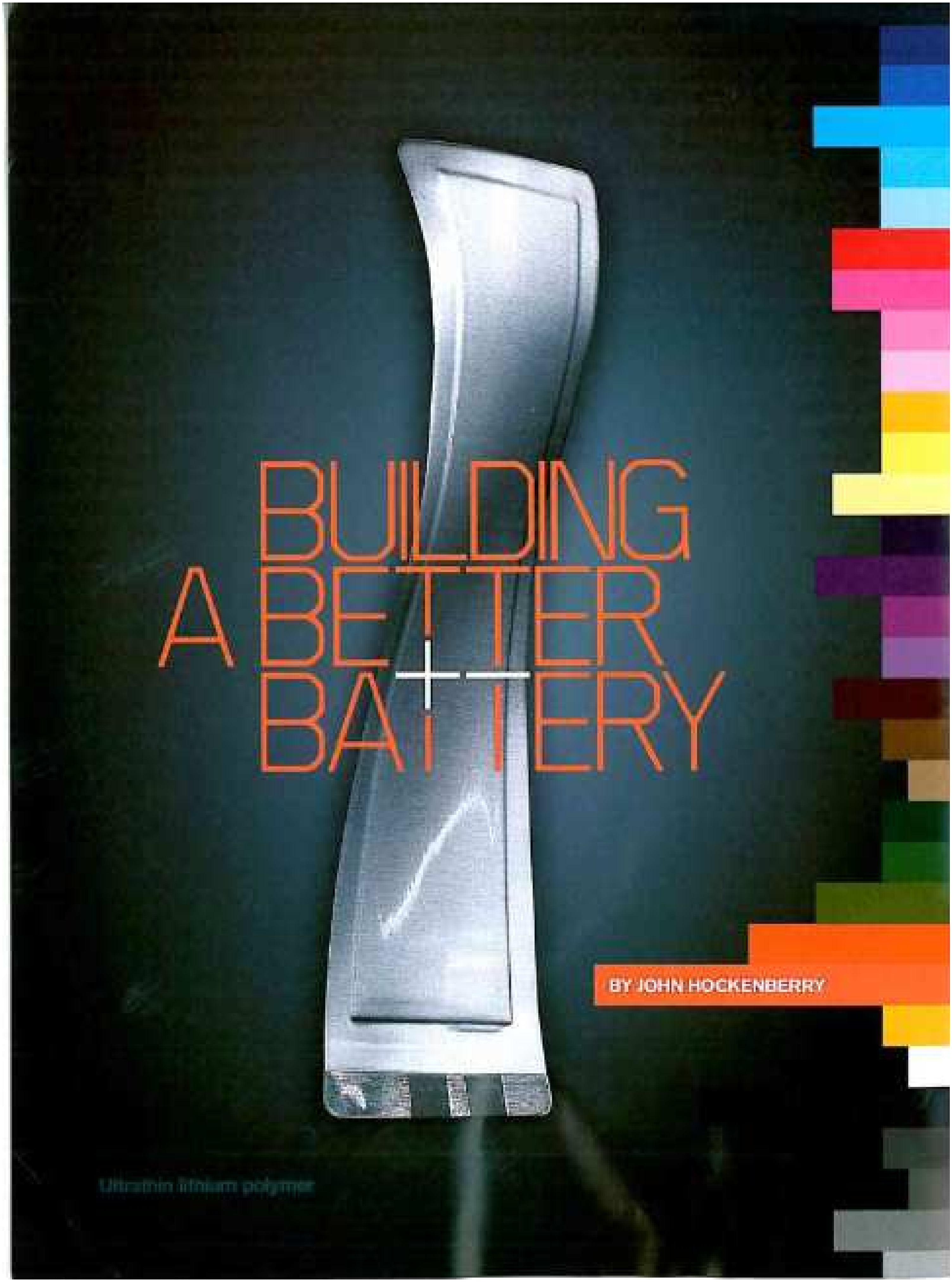
BUILDING A BETTER BATTERY

BY JOHN HOCKENBERRY



Ultrathin lithium polymer

PHOTOGRAPHS BY MARTIN TIMMERMAN

Single-use alkaline

THEY RUN OUT OF JUICE – OR BURST INTO FLAMES – AT EXACTLY THE WRONG TIME. CAN'T ANYONE MAKE A BATTERY THAT DOESN'T SUCK?

Building a Better Battery

They run out of juice – or burst into flames – at exactly the wrong time. Can't anyone make a battery that doesn't suck?
By John Hockenberry

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How to power the laptop of the future

ON A HOT JULY DAY AT A FOOD PACKAGING COMPANY in Vernon Hills, Illinois, Henrik Gustavsson sat at his workstation tweaking electrical drawings for an industrial juice-making machine. He looked up and noticed an odd haze at the far end of the office. A coworker shouted, "Hey, there's a fire!" Gustavsson rushed over to join the crowd gathering around a Dell Latitude laptop sitting on a desk in its docking station. "There was smoke coming out of the sides," the 26-year-old engineer recalls. "As I got close it actually started popping, and a flame shot straight up into the air." To Gustavsson, the closed, burning laptop looked like an overheated George Foreman grill. It smelled horrible – not surprising, since it was cooking up an LCD-keyboard-melt sandwich.

Gustavsson snapped some photos as colleagues sprayed the burning Dell with foam from a fire extinguisher. "That thing did not want to go out," he says. "We had to zap it three or four times." They then carefully carried the laptop out to the front sidewalk and waited for the fire department to arrive. When nobody was looking, Gustavsson pried the smoldering, melted carcass open to find a 5-inch hole where the lithium-ion battery had been. "It was pretty awesome," he says. That night, he posted his pictures to the nerdy Web site Tom's Hardware. The images received more than 80,000 hits over the next week.

It was a long, hot summer for lithium-ion batteries this year. Stories of Dell laptops spontaneously combusting dominated tech news. One computer set fire to a Ford pickup in Nevada; another ignited in the overhead compartment of a Lufthansa flight as it sat on the tarmac at Chicago's O'Hare airport. A video of a Dell that exploded spectacularly during a business meeting in Osaka began making the rounds on the Internet. In mid-August, the US Consumer Product Safety Commission announced that Dell had agreed to recall 4.1 million Li-ion batteries – the largest battery recall in history. Nine days later, Apple asked its users to return 1.8 million more Li-ion packs. Then, in September, Toshiba recalled 340,000 batteries. Sony, which manufactured the batteries for all three companies, will spend an estimated $250 million replacing them.

The technical term for these bizarre incidents is thermal runaway. It occurs when the touchy elements inside a Li-ion battery heat up to the point where the internal reaction accelerates, creating even more heat. A sort of mini China Syndrome of increasing temperature builds until something must give. In the case of a laptop flameout, the chemicals break out of their metal casing. Because lithium ignites when it makes contact with the moisture in the air, the battery bursts into flame.

Exploding notebook computers are, of course, extremely rare. There are just a handful of documented cases, even though an estimated 1.8 billion Li-ion cells are in circulation. Sony claims the latest conflagrations were caused in part by trace amounts of metal accidentally left inside the batteries during the manufacturing process. The company adds that problems are also caused by laptop makers placing batteries too close to internal heat sources like CPU chips.

But such technical excuses sidestep the fact that flammability and heat intolerance are long-standing problems that have plagued Li-ion batteries since they were invented almost 30 years ago. And as devices have gotten smaller in size but richer in features, things have only worsened. Forced to produce more energy in less space, Li-ions die faster (as early iPod owners found when their batteries wore out long before their players did), and their propensity for thermal runaway greatly increases.

Lithium-ion technology may be approaching its limits. Batteries conform to technical restrictions set by nature and don't obey Moore's law like most of the digital world. In the last 150 years, battery performance has improved only about eightfold (or less, depending how it's measured). The speed and capacity of silicon chips, of course, improves that much every six years. "Li-ion is an extremely mature technology, and all of the problems are known by everybody," says Art Ramirez, the chief of device physics at Bell Labs. "They aren't going to change."

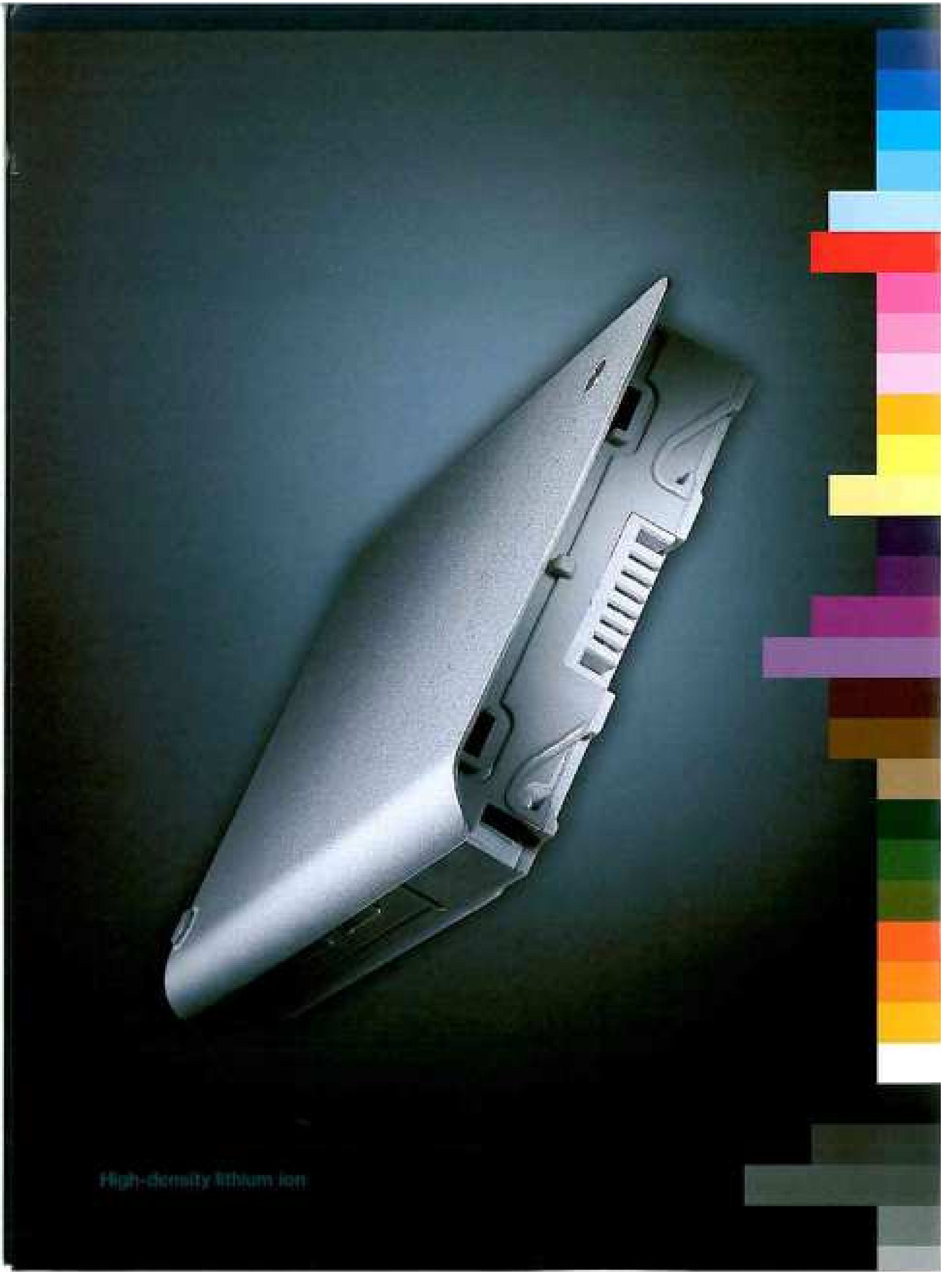
If Li-ion technology is at, or even near, its maximum potential, gadget makers (and users) are in trouble. Li-ion – with its high power, fast recharge times, and steady voltage – is the best battery the consumer electronics industry has. It powered the 50 million laptops, 800 million cell phones, and 80 million digital cameras sold in 2005. If the technology stagnates without a viable replacement, so will every kind of portable device, from ThinkPads to Game Boys.

So the hunt is on for a better battery. And it's just not the usual Asian giants – Sanyo, Sony, Toshiba – on the prowl. Tyco, Lucent, Intel, and venture capital firms like Draper Fisher Jurvetson are among those pumping millions of R&D dollars into battery startups and research labs. Of course, kicking the lithium habit won't be easy. Possible successors like fuel cells have been heralded for decades, but design, implementation, and cost issues have prevented them from reaching our Nokias and MacBooks. Yet, to get the juice they need, gadgets will almost certainly require something totally new. We'll need more than just better batteries; we'll need to rethink the way all portable electronics are designed and made.

IN THE MID-1800S, French inventor Raymond Gaston Planté created the first rechargeable battery, a combination of sulfuric acid and strips of lead foil.

People thought of Planté's creation as a "box of electricity" or an electric fuel tank. It's an analogy we make to this day: The scientific symbol for a battery is still a fuel-tank-like box. But the metaphor is not apt. You don't fill a battery with electrons that are sucked out later, only to be replaced ("Fill 'er up.") with more electrons. A battery is more like a complicated and finicky chemical pump that exploits what happens when certain materials (mostly metals) are placed together in an electrolyte solution. All batteries – watch, flashlight, cell phone, car – work basically the same way. Negatively charged electrons are chemically stolen from a metal anode and flow rather desperately toward a positively charged metal cathode at the other end of the circuit. Voltage is a measure of the force pushing the electrons from pole to pole, while current is the number of electrons speeding by a given point. Together these attributes establish the power of a battery. Current can be altered by changing a battery's size, but voltage is determined (and fixed) by the atomic makeup of the materials used. Those attributes, recorded in the good old periodic table of elements, were configured shortly after the big bang and are not subject to clever human modifications.

In "Building a Better Battery" (issue 14.11), a Rayovac flashlight battery was pictured above text about computer batteries bursting into flames. The layout was not intended to suggest that Rayovac batteries have caused computers to explode or that they are defective in any way. We regret any inference created by the photo.



High-density lithium ion

Plus:

How to power the laptop of the future

The first widely produced batteries were lead acid. Used in early cars, they got the automobile to start as reliably as the horse. By the 1960s, engineers had developed lighter, single-use alkaline and mercury batteries, making portable transistor radios and two-way communication devices possible. In the 1980s, compact rechargeable batteries were developed using nickel and cadmium. Originally used by the military and NASA, NiCads eventually reached the consumer market, giving us video cameras, the first laptops, and cordless power tools. The power cells were reliable but suffered from an annoying glitch dubbed the memory effect: If users didn't fully charge the batteries on initial use, the cells could "remember" only their original partial charge. This was fixed by the development of nickel metal hydride. NiMH packed more power, had less memory effect than NiCads, and recharged faster.

Scientists long knew that lithium would make an excellent anode. Most battery chemical combinations deliver 1.2 to 2 volts. But when paired with the right cathode, lithium atoms practically spew electrons, delivering the highest nominal voltage of any element in the periodic table: 3.6 volts per cell. (Multiple low-voltage cells can be strung together to achieve the same punch – that's how you get 9-volt batteries – but this adds weight and bulk.) Lithium tends to explode on contact with air, however, which made research difficult. In the 1970s, a US scientist with the ironic name John Goodenough (batteries never are) finally figured out how to tap the electron potential of lithium: Combine it with cobalt. Then all it took was a manufacturer willing to spend the money required to safely mass-produce the new batteries. Sony grabbed the opportunity in the '80s, producing a rechargeable lithium-ion pack for a video camera. These batteries were the first rechargeable cells to exceed the energy of single-use alkalines. They had no memory effect, four times the energy of NiCads, and twice the energy of nickel-metal-hydride cells. A new era had begun.

Throughout the '90s, Li-ions enabled a host of advances. Laptops could be made lighter and were able to power backlit screens and bigger hard drives. Cell phones could be smaller. The MP3 player was born. But these new devices hungered for more and more power. While a flashlight or a car starter places simple demands on a battery, powering a computer or camcorder is much more complicated. These devices contain dozens or even hundreds of individual components, and LCD screens have different voltage and current needs than, say, hard drives or Wi-Fi chips. So voltages are stepped up or down using transformers and other circuits, resulting in enormous losses in efficiency. The more complex a device, the harder the battery has to work.

Furthermore, because digital calculations require steady voltages to maintain memory, power fluctuations can be disastrous. So modern batteries are designed to operate in a narrow range where they can deliver constant output. To keep voltage steady and at effective levels, a battery must be packed with lots of extra power. There's really no such thing as a dead battery anymore; even when a cell registers empty, it still has plenty of juice in it – just none in the usable range. Battery-industry veteran Mike Mahan puts it this way: "It's like you have a 20-gallon tank and you can use only 5 gallons, but you still have to drive around with 15 gallons anyway."

Squeezing enough power into compact Li-ion cells to deal with these issues requires serious safety equipment. Today, most Li-ion cells contain at least two – and sometimes three – separate countermeasures to keep the reaction from getting out of control. According to Glen Wensley, chief polymer chemist at batterymaker Solicore, these safeguards can represent as much as 30 percent of the engineering and perhaps half the cost of a standard lithium-ion battery. "It's an extremely unstable system, and so you need a voltage limiter, a current fuse, and a third safety system, which is actually internal to the battery. It's called a separator, which physically separates the battery to prevent thermal runaway." The first two systems keep the battery from overcharging or over-discharging. The third is a kill switch: All batteries have a porous separator between the anode and cathode to keep the reaction from happening too quickly. In most Li-ion cells this component completely solidifies if it gets too hot. It's a kind of electrical suicide that destroys the battery to cool it down. These defenses are one reason that thermal runaway is extremely rare.

FLAMING LAPTOPS may be dramatic, but to Sony they are mostly a PR headache. The company's main concern is still squeezing more power out of smaller Li-ion battery packs. Case in point: the company's ultraslim family of digital cameras. Product designers managed to cram an advanced imaging sensor, processor, and LCD into a 0.9-inch-thick shell. And the battery? "One of the most difficult things about that camera was the damn battery," says Mike Kahn, a senior product manager at Sony. "It had to be thin, and it had to be powerful." Eventually, Sony solved the problem by giving the battery its own chip. "The battery constantly talks with the processor to minimize power use and avoid waste," Kahn says.

Sony sees its success with cameras as a sign that lithium-ion technology still has more than a little life left in it. Last year, Sony unveiled the Nexelion, a so-called lithium hybrid that pairs lithium with tin for the first time and claims a 30 percent capacity increase over previous lithium-ion cells. The batteries were first offered in new Sony Handycams last summer. Keeping pace, Toshiba also announced a higher-powered Li-ion battery last year.

These improvements, however, won't really keep up with consumer demand for more power. Nowhere is this more apparent than in laptops. "The industry wants dual-core processors and an eight-hour run time with no increase in size and weight," says Valence Technology's Jim Akridge. "It doesn't look like that's going to happen."

One way to keep up with power demands is to go back to the periodic table. Lithium offers the highest voltage of any element, but lower-voltage metals don't explode and may ultimately be able to hold more power. Among the companies betting on tamer elements is Zinc Matrix, a startup run by Ross Dueber – a former Air Force major who used to design advanced nickel-cadmium batteries for the military's Strategic Defense Initiative.

Plus:

How to power the laptop of the future

Dueber and his team have come up with a power cell that runs on silver and zinc and uses stable, nontoxic water as an electrolyte. The company claims it has solved manufacturing difficulties associated with previous silver-zinc efforts and boasts that its cell offers a 50 percent increase in run time over lithium ion, with none of the safety issues. But because silver-zinc has a lower voltage, these batteries must pack lots of cells together to achieve the industry standard of 3.6 volts. This makes the batteries heavy – a serious drawback. Dueber's plan for overcoming this is to convince devicemakers to retool their products to run at lower voltages. "Our first battery will simulate lithium ion, but eventually we hope to be designed into the future," he says.

In September, Zinc Matrix demonstrated a six-hour prototype for an Intel-based laptop. If all goes well, Dueber says, that battery could be on the market by the end of next year. Among those funding the effort are Tyco Electronics and Intel. Dueber says he has received about $36 million to date.

At best, though, Dueber's battery is only a sort of electrochemical methadone – same addiction, just slightly longer-lasting, with no flameout. No matter how much the industry toys with a single box of electrons, it will eventually encounter the same predictable roadblocks: too many components demanding too much power for any one battery. That's why Solicore decided to think small.

Based in Lakeland, Florida, Solicore is developing Li-ion batteries in ultracompact forms that can sneak into places batteries have never gone before. This might allow Solicore's cells to act as secondary batteries in a device. For example, one could be slipped behind a laptop's screen, where it would power just the backlight, taking some of the load off the main battery. To make such versatile Li-ion cells, Solicore has developed a new type of lithium polymer.

Lithium-polymer batteries use an advanced gel rather than a liquid to separate the cell's positive and negative poles. Solicore's proprietary polymer restricts electron flow so it can't be disrupted by heat or even a violent blow from a hammer, which means the batteries won't get caught in a thermal runaway cycle. This lets engineers make batteries without standard safety features, which means they can be made in virtually any shape or thickness. Some of the early models are as thin as sheets of paper, essentially printed and cut like credit cards. In fact, they are already being used to power a new breed of smartcards, which come with their own onboard display and may someday even have wireless capability. Solicore is working with Visa and others to bring the cards to market next year.

STANDING AMONG THE VOLT meters, electrical wiring, and beakers full of various electrolytes in his Bell Labs research facility, physicist Tom Krupenkin holds a partially etched disc of silicon. Nearly all of its surface is empty. In one corner, there's a micron-scale pattern of posts that, under a microscope, looks like a hyper-orderly lawn. It's called nanograss.

Krupenkin, a Russian-born scientist with PhDs in materials science and in physics, is one of a growing number of researchers who think consumers and gadgetmakers need to take a more radical approach to battery design. In his eyes, playing around with new chemistry or mysterious polymer goop won't deliver the kind of exponential growth the industry needs. "In the traditional battery world, there is nothing new anymore," Krupenkin says. "There has to be a different way to think about these devices, different processes brought to bear."

Krupenkin thinks he has found such a process – something that will be more than just a quick fix. Instead of sealing an unstable reaction in a big box, he and his team – a combination of Bell Labs scientists and researchers at a startup called mPhase Technologies – are designing tiny batteries out of nanograss that can be turned on and off chemically. Such precise control, they argue, would let them take the idea of multiple batteries a step further. Krupenkin's vision is that future gadgets would behave like biological systems, in which cells carry their own power instead of relying on a single primary energy source for the whole organism.

Nanograss, Krupenkin explains, is superhydrophobic, or massively water resistant. Fluids deposited on the tiny silicon posts are practically frictionless. A droplet of water remains spherical on the nanograss. But when Krupenkin applies an electric charge between the droplet and the silicon, the droplet disappears. The current has disrupted the water's surface tension, causing it to fall into the nanograss, where it's held firm by the tiny posts. Krupenkin calls this "electrowetting." Apply another tiny current across the conductor and the water molecules heat up, causing the droplet to rise back to the top of the nanograss, where surface tension once again keeps it in a nearly perfect sphere.

The idea is to marshal this electrowetting to fine-tune a battery's internal reaction – regardless of what the battery is made of. The nanograss would hold a battery's electrolyte away from the reactive metal when no power is needed, then release it when it's time to turn on. This type of structure would free device manufacturers to distribute fields of tiny batteries deep into their products. Components could pop on and go to sleep as needed. Rechargeable nanograss would be controlled by the microprocessor, which would manage exactly how much power each system needs. And because each component would have its own power bank, the built-in inefficiencies of the single-voltage, single-power design would vanish, driving down costs and potentially increasing battery life by an order of magnitude for the first time in 100 years.

The problem is that product makers would have to retool and redesign almost all their devices to take advantage of these minute, chip-controlled batteries. It's a hurdle that Krupenkin and his team know could take years to get over. But they also know that sooner or later, gadgetmakers will want more than lithium-ion batterymakers can provide. As Bell Labs' Ramirez puts it, current battery problems point to the end of the "silicon road map." As computers shrink to the molecular level, the whole architecture of portable devices needs to change. "The end of the silicon road map will show that there have to be other ways of doing things. At some point, it will become economically viable to invest in radical new strategies," he says. Sooner or later, solutions like nanograss are going to look awfully good.

Plus:

How to power the laptop of the future

A hundred years ago, just down the road from Krupenkin's lab in northern New Jersey, Thomas Edison struggled to mass-produce batteries that would be safe and reliable. Reportedly, he was so stymied by uncooperative chemistry that he once asked a psychic to tell him the best chemistry for a storage battery. In a prickly comment to a colleague at General Electric in 1900, he said, "I don't think nature would be so unkind as to withhold the secret of a good storage battery if a real earnest hunt for it is made. I'm going to hunt."

The hunt is still on.