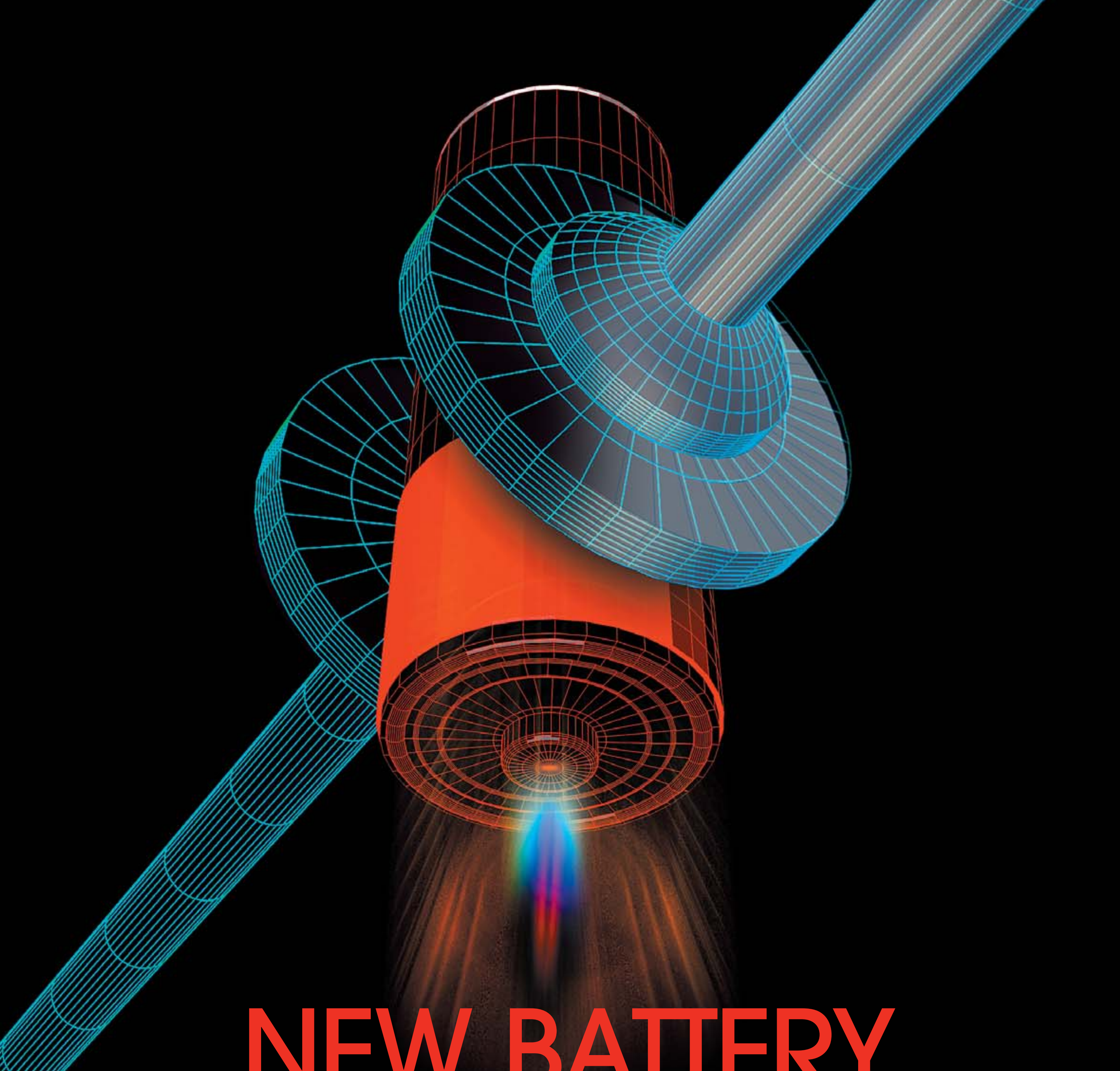

NEW BATTERY TECHNOLOGIES HOLD PROMISE,

PERIL FOR PORTABLE-SYSTEM DESIGNERS

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FOR THE NEAR FUTURE, MOST PORTABLE SYSTEMS WILL HAVE TO RELY ON SOME FORM OF THE NOW-VENERABLE LITHIUM-ION BATTERY. FORTUNATELY, LITHIUM-ION CELLS ARE IMPROVING IN COST, ROBUSTNESS, AND EVEN ENERGY CAPACITY. BUT BEWARE THE PERILS THAT "CLONE" BATTERY PACKS CAN POSE FOR YOUR SYSTEM.

For portable systems relying on a battery or a battery pack, the ever-increasing complexity and speed of the system's ICs and the resulting increase in power requirements are problematic: Although ICs can surf the processing and speed wave of Moore's Law, battery technology has improved at a much slower pace. The increase in energy capacity for a lithium-ion cell has little more than doubled in 10 years, from 280 Whr/l (watthours per liter) in 1995 to 580 Whr/l in 2005. Compare this figure with the IC's ability to double its complexity every 18 months, and you can see the mismatch between power need and power capacity for portable devices.

Although batteries don't enjoy the gee-whiz aura of the IC, lithium-ion technology has nevertheless made significant advances. By changing the chemical formulation of the cathode and anode, lithium-ion-battery manufacturers are tweaking cells' energy capacity, as well as cell cost and robustness. However, even as vendors make advances, variations will emerge. System designers will need to pay attention to battery formulations and be aware that battery charging and output voltages are changing, affecting system requirements.

Lithium ion is not the only type of rechargeable cell that battery packs use. Older but still popular types are NiMH (nickel metal hydride) and NiCd (nickel cadmium). Lithium ion, which manufacturers introduced in 1991, is the newest technology, but it has taken over the field with its combination of relatively low cost and high energy density (**Table 1**). (For a definition of battery terms, such as "cell" and "pack," see **sidebar** "A battery of definitions.")

What's been driving the change in lithium-ion chemistry? In addition to the need for higher power density, battery manufacturers want a cheaper formulation as well as a safer, more robust mix. Tweaking the lithium and other chemicals in a battery cathode affects the battery cost, capacity, ruggedness, and voltage.

In today's lithium-ion cells, which typically come in a 18650-size cyclindrical package, the anode is a graphite mixture, and the cathode is a combination of lithium, nickel, and cobalt. When lithium batteries first became available in the 1990s, cobalt was relatively inexpensive, and its price was stable. But cobalt prices began to rise at the end of the decade, and battery manufacturers

AT A GLANCE

- Plan on lithium-ion cells' continuing as the dominant power sources for portable consumer electronics, such as laptops and cell phones.
- Some lithium-ion batteries will change both their charge voltage and their output voltage.
- Higher voltages, which can damage both older battery packs and device electronics, will necessitate battery authentication to protect users from substituting old and potentially unsafe battery technologies.

worked on new cathode materials that moved away from cobalt.

According to Robin Tichy, product-marketing engineer with Micro Power, a battery-pack developer that incorporates cells from several manufacturers in its packs, "The road map for lithium-ion batteries based on current $LiCoO_2$ (lithium-cobalt-dioxide) formulations is that vendors are phasing out 2 Ahr, 2.2 Ahr is currently in production, and 2.4 Ahr is coming into production." Tichy says that manufacturers are evaluating 2.6-Ahr technology and planning 2.8-Ahr technology. "When you hit 3 Ahr, you reach the theoretical maximum for lithium cobalt dioxide in the 18650 cell," she says.

In addition to its relatively high cost, Tichy points out, cobalt is chemically more volatile than other potential cathode materials, such as nickel and manganese. "Nickel is less volatile, both economically and chemically, than cobalt," she says. "However, it's also much less efficient at charge cycling. Manganese is cheap and safe with good [high-current]-rate capabilities. Manganese's drawback is that it has poor energy density and is slightly soluble in an electrolyte."

The first alternative to lithium cobalt dioxide that will appear in an 18650 cell will have a cathode with a solid solution of NCM (nickel-cobalt manganese). Manganese and nickel replace some, but not all, of the cobalt in a partial phasing-out of the cobalt material, resulting in a better battery price but no additional energy capacity.

Because the cell voltage is due to the difference in the electrical potential between the anode and the cathode, a change in cathode material changes the cell-output voltage. Although the NCM formulation increases cell voltage by only about 0.1V, that increase is still enough to make an impact on the host design. And NCA (lithium-nickel-cobalt-aluminum dioxide), a formulation coming hot on the heels of NCM, will have an even greater differential.

Due at the end of 2006, NCA is another formulation from Panasonic. The formulation is similar to NCM, but it has more nickel, and aluminum replaces manganese, which also connotes less volatility and explosive potential, says Tichy. "The other advantage is that the more nickel you put in, the higher the capacity will be." At 620 Whr/l, NCA provides the industry's highest energy density. Correspondingly, the cell's output voltage will probably be 3.6V.

In addition to the higher output voltages of the new battery chemistries, the batteries charge at a higher voltage, posing a problem for systems that provide a system charger that must be able to distinguish the battery type before charging at the higher voltage. Brian Barnett, managing director at Tiax LLC and conference chairman of the Portable Power 2005 conference, says, "Rather than having a simple world when there were not a lot of versions of lithium-ion batteries, we're headed in the direction of having numerous versions that don't have the same terminal characteristics. If you took today's 4.2V lithium-cobalt-dioxide technology and you accidentally put that into a charger that was not smart enough to recognize the different chemistry, you could have a very serious incident." System designers can guard against a user's charging cells with the wrong voltages by implementing authentication circuitry in their pack (**Reference 1**).

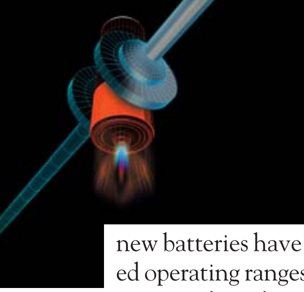
Dave Heacock, vice president of Texas Instruments' portable-power-management business, sees a lot of electronic-system designers trying to squeeze every last bit of power from the system battery pack. "The battery can be a point of differentiation in the marketplace if it's done well, and the extra little money you pay there goes a long way toward making your system sell," he says. The new lithium-ion-battery formulations are attractive but also can introduce variations into battery-performance characteristics that weren't there before. "A lot of the battery manufacturers' efforts are in trying to squeeze more out of the same space and in trying to make the cell safer. When they first develop a cathode or an anode, they often have some difficulties in having it perform to the same level as some of the more mature chemistries," he says. The

BATTERY MANUFACTURERS' EFFORTS ARE IN TRYING TO SQUEEZE MORE OUT OF THE SAME SPACE AND IN TRYING TO MAKE THE CELL SAFER.

TABLE 1 MOST POPULAR RECHARGEABLE-BATTERY TECHNOLOGIES AND THEIR CHARACTERISTICS

Battery chemistry	Energy density (Whr/kg)	Charge cycles	Self-discharge rate (%/month)	Special disposal
Nickel metal hydride	60 to 120	200 to 1000	30	No
Nickel cadmium	45 to 80	700 to 1300	20	Yes
Lithium ion	110 to 250	500 to 1000	0 to 10	Yes

Courtesy NanoMarkets, "Micro Power Sources: Opportunities from Fuel Cells and Batteries for Mobile Applications," September 2005.



new batteries have such severely restricted operating ranges that system designers may need to choose a battery pack that has built-in battery-management circuitry, such as authentication.

But system designers can't just hand off all battery-pack decisions to their battery-pack vendor. Heacock cautions, "Make sure you know what's inside," especially regarding the cells themselves. The process technology for lithium-ion cells, especially among the long-time companies, such as Sanyo, Panasonic, and Sony, are well-established, and production results are repeatable. However, for newer battery manufacturers, often the hungry Chinese manufacturers, variance in battery specifications, such as temperature versus discharge rate, can vary wildly from cell to cell. "Newer companies compete on price, so make sure you know what you're getting for that price. Ask how stable their cell-to-cell variance is," says Heacock.

A BATTERY OF DEFINITIONS

***Lithium ion*: This technology is the most popular rechargeable-battery technology for most consumer products. Lithium is the lightest metal and provides the highest energy density of all battery formulations; however, it is also highly reactive and unstable during charging. Batteries almost universally use lithium ion, a more stable form. However, its ionic form is still explosive in certain conditions. (For a graphic depiction of lithium-ion cells subjected to overcurrent conditions, see the "Techflicks" sidebar in Reference A.)**

Lithium-polymer cells have similar specifications to those of lithium-ion, but they feature a semi-rigid and thin form factor with only half the lifetime. Their "flexibility" is often misleading, because lithium-polymer cells should remain flat when you install them in a device, not even bending for installation in the battery system. They are also more expensive (Reference B).

***Nickel-based batteries*: The two most popular are NiCd (nickel cadmium) and NiMH (nickel metal hydride). Nickel cadmium can provide a high drain rate, which makes it the incumbent technology in power hand tools. For example, a power drill pulls a large current to provide sufficient torque. However, due to cadmium's toxicity, manufacturers are phasing out nickel cadmium when possible because of ROHS (reduction-of-hazardous-substances) requirements. NiMH is popular in low-cost systems, such as cordless phones. Advances in high-drain capabilities, as well as low cost, mean that lithium ion is moving into both NiCd and NiMH territories.**

***Cell*: A cell is a battery used only in battery packs. The most popular lithium-ion cell is the 18650, an 18-mm-diameter, 65-mm-long cylinder (Figure A).**

Figure A The most popular lithium-ion cell is the 18650, an 18-mm-diameter, 65-mm-long cylinder.

***Battery pack*: A battery pack is a set of cells and their protection/authentication/security circuitry (Figure B). Most lithium-ion rechargeable batteries are battery packs containing one cell, such as those in cell phones, or as many as four cells, such as those in laptops. Battery packs are more than just convenient ways of matching and packaging cells: The requirements for lithium-ion-safety specifications are such that the pack is necessary to package safety circuits into the device. Even a device requiring only a single lithium-ion cell uses a single-cell pack, with the security circuits around the cell, and the whole unit shrink-wrapped or encased in plastic. A single-cell battery pack, such as the one in a cell phone, requires 7 to 8W; a four-cell pack in a laptop requires 35 to 70W.**

Figure B Battery packs package lithium-ion cells and any authentication circuitry into a sealed unit.

***Charge cycle*: Most lithium-ion batteries are fast-charged to 80% of their capacity and then trickle-charged to full capacity. One charge cycle uses all of a battery's power but not necessarily from a single charge. For example, if a device discharges to half its power and then fully recharges, and it repeats this cycle the next day, it would count as one charge cycle. Each time a charge cycle completes, the battery's capacity diminishes slightly.**

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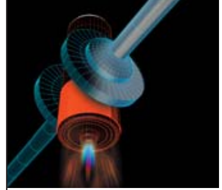

Tichy agrees. "Once the new formulations, such as NCM, start to become available, we're likely to see variations among all vendors," she says. "Variations in cathode formulations may yield differences between vendors' offerings: There may be a slightly different voltage depending on the exact mixture of each vendor." Each manufacturer will designate its cell's operating voltage and give customers the curve they can expect. But, if the pack vendors design a pack for one supplier's cell, it may not be able to get a second source for the new formulation.

Heacock lists useful information available from smart-battery packs with authentication capability, such as cell-ID number, overvoltage rating, temperature reporting, and remaining capacity. He points out that this information becomes important when system designers struggle to make one system work for a variety of users. "Batteries act differently depending on their environment," he says. "For example, an MP3 player in an air-conditioned office experiences different battery response from a player that is left in a car during the summer months. The difference in performance may upset the user who may blame the unit's battery. But if you can design the battery system to allow for the differences in how consumers use them, the batteries seem to be acting the same."

In addition to allowing for system environments and the effect they have on battery performance, designers have to assume that an end customer may use an inappropriate battery pack in a quest to economize on a replacement or backup pack. Gene Armstrong, managing director of thermal and battery management for Maxim, describes a likely scenario: "We have customers who are planning on switching over to the new cells with higher charge voltage of 4.4V, but this change can cause problems from a safety standpoint, because the minute they switch over [to the new cells], there will be a clone battery pack available from some unknown source, using cells with the old technology that charges at 4.2V. If the charging system applies the 4.4V to the old cells, it's potentially a dangerous situation." Authentication devices in the pack can prevent charging circuitry from applying an overvoltage to an after-market clone pack.

Most lithium-ion-battery packs go into laptops and cell phones. According to Tiax's Barnett, these two applications consume more than 80% of lithium-ion-cell sales. However, yet another new cathode formulation is evolving that will make lithium ion practical for high-current applications, such as rechargeable portable power tools, which nickel-cadmium technology currently dominates. $LiMn_2O_4$ (lithium-manganese-oxide) technology has the potential to reach 300A for short pulses of a second or two. (The typical lithium 18650 cell today can support a 4 to 6A pulse.) The new cell can extend 80A for about 10 seconds. Currently, nickel cadmium is the incumbent technology for power tools because of its ability to support a high drain rate. However, nickel-cadmium batteries run afoul of ROHS (reduction-of-hazardous-substances) and WEEE (waste-from-electrical-and-electronics-equipment) legislation, so look to the new lithium formulation of lithium manganese oxide to gradually replace nickel cadmium in power tools. EDN

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