Rethinking Ink

Printing the pages of an electronic book

By IVARS PETERSON

As a display technology, ink on paper has many advantages. You can carry it around and read it almost anywhere, whether as a single sheet or packaged as a newspaper, magazine, or book.

Ink doesn't require an external power source or an expensive, fragile screen, and it doesn't suffer software and hardware glitches.

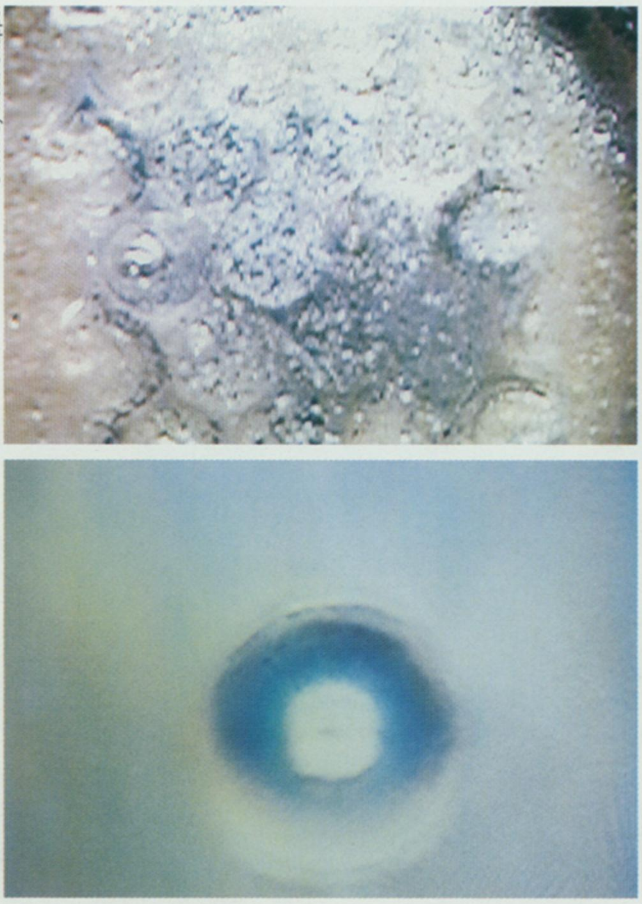
Information printed on paper can't be updated, however, says Joseph M. Jacobson of the Massachusetts Institute of Technology's (MIT) Media Laboratory.

One answer to those shortcomings may be a hybrid display system that combines the flexibility and versatility of paper with the chameleon nature of a conventional computer monitor and the high capacity of electronic data storage. The key to such an innovation, Jacobson says, would be a new type of ink— one that can change from black to white or white to black on command.

Printed with such an electronic ink, a book would become a sheaf of high-resolution, high-contrast, electronically addressable displays. As with an ordinary book, a reader would be able to leaf through the pages, browsing the contents, making comparisons, and marking pertinent passages. In addition, however, a reader could adjust the format of the pages for readability, update the book's contents, or even download a whole new text.

Indeed, printing on paper and other materials primed with electronic ink offers the prospect not only of digital books and regularly updated newspapers but also of endlessly customizable wallpaper, billboards, product labels, and even T-shirts and bumper stickers.

Over the years, several research groups have investigated various schemes for producing and deploying an ink that changes its color in response to electric signals. Now, MIT finds the process Jacobson and his coworkers have developed promising enough to file patents, and a newly formed company has licensed the pending patents to commercialize the laboratory results.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Top: An early prototype of a paper surface covered with microcapsules of electronic ink. Bottom: Closeup showing the two-colored particle inside an electronic-ink microcapsule.

The letters that comprise the words on a page of this magazine (and just about any other modern print publication) are made up of tiny, closely spaced dots of ink. The ink is a light-absorbing pigment firmly affixed to the light-reflecting paper surface.

The symbols or images on a computer screen are likewise composed of minuscule dots, called pixels. Unlike the dots of ink on paper, the pixels on a computer screen respond to electric signals, changing readily from bright to dark or dark to bright to create whatever pattern is required at a given moment.

In a cathode-ray tube display, a scanning electron beam causes phosphors to glow at selected spots. In a liquid crystal display, an array of transistors controls the electric field applied to individual cells, changing their transparency.

Compared with ink on paper, cathode-ray tubes and liquid crystal displays are bulky and heavy, and they consume considerable amounts of power. Jacobson's task was to find a way to achieve electronic control of dots printed on a paperlike sheet—in effect, obtaining a thin, low-power, low-cost display. He and his coworkers turned to microencapsulation technology, which packages tiny parcels of gas, liquid, or solid within some other material.

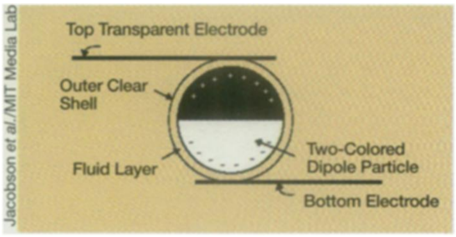
Coating a magazine page with microcapsules filled with perfume, for example, forms the basis of scratch-and-sniff perfume advertisements. Microencapsulation also plays a significant role in the detergent, pharmaceutical, and baking goods industries.

Jacobson's scheme involved encasing microscopic particles within tiny, fluid-filled, transparent capsules, laid out in an array to cover a sheet. The researchers used spherical particles that are black and positively charged on one side and white and negatively charged on the other.

Momentarily applying an electric field to an individual capsule rotates the enclosed particle and brings its white side to stick at the top of the microcapsule. An opposite electric field rotates the particle to the black side and pushes it to stick at the bottom. No additional power is required to keep the particle in position and, hence, maintain an image.

In the complete assemblage, an upper, transparent layer printed with a web of digital signal–processing microcircuitry would control a lower layer of electronic-ink microcapsules.

Initially, the researchers used particles



Jacobson et al./MIT Media Lab

Schematic diagram of the system used to control an electrically charged particle within a microcapsule.

about 250 micrometers (μm) in diameter, which permit a display with a resolution of 100 dots per inch—a lower resolution than today's laser printers typically provide. Subsequently cutting the particle size to roughly 40 μm represented an important step toward fabricating working displays with an acceptable resolution and a thickness of about 200 μm (approximately 2.5 times the thickness of a sheet of paper).

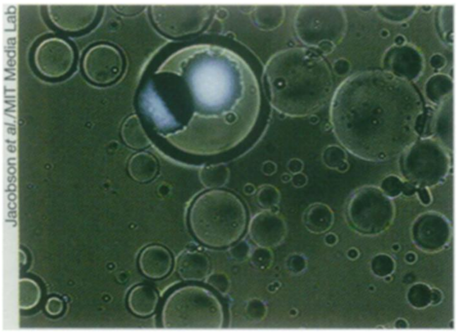
Jacobson and his team have now demonstrated that their ideas work on a laboratory scale. Producing electronic-ink displays of sufficient resolution and robustness for an electronic book, however, remains years in the future.

Other materials also provide potential candidates for electronic ink. Paul R. Kolodner of Bell Laboratories at Lucent Technologies in Murray Hill, N.J., and his collaborators have focused on a protein molecule known as bacteriorhodopsin.

"Natural materials often perform very complex functions that cannot be easily obtained from manufactured materials such as semiconductors," Kolodner notes. Moreover, because organisms manufacture the biological materials by themselves, one can obtain a steady supply simply by providing food and harvesting the products.

Bacteriorhodopsin is found in the intensely purple cell membrane of a bacterium called *Halobacterium salinarium*, which grows in salt marshes. Illuminating the protein triggers a photochemical reaction cycle, which transports protons along a channel spanning the cell membrane.

The membrane's purple color comes from a bacteriorhodopsin component called retinal, which is strongly bound to an amino acid inside the membrane channel. Unbound retinal in solution is pale yellow.



Jacobson et al./MIT Media Lab

Micrograph of an encapsulated, two-colored electronic-ink particle.

Alternating laser light of two different wavelengths on the protein molecule can switch it back and forth between its purple and yellow forms. That behavior has prompted research on the use of bacteriorhodopsin as the light-sensitive element in artificial retinas and as memory or processing units in protein-based or optical computers (SN: 3/8/97, p. 140).

A thin film of bacteriorhodopsin can also change its color in response to an external electric field. In normal bacteriorhodopsin, such a field causes a low-contrast color change from purple to blue. However, certain mutant bacteria make a form of bacteriorhodopsin that changes from blue to pale yellow in a strong electric field.

Sandwiching such a protein film between transparent plates that incorporate a large number of electrodes can produce a display. By applying appropriate voltages to different parts of the film, it's possible to write a page of text or place an image on the screen.

Like ink on paper, images on a bacteriorhodopsin display are visible in ambient light. The protein film also provides high contrast and switching times as short as 200 microseconds, Kolodner says.

The main difficulty at present is that it takes a rather substantial electric field at several thousand volts to trigger the color change. "We are still working on the project," Kolodner says, "but until we make a breakthrough with a pigment that is much more sensitive to external fields, this will not become a technology."

The MIT approach has progressed much farther, and the institution has applied for patents on various aspects of the electronic-ink process and an electronic-book system developed by Jacobson and his team.

A company called E Ink Corp., based in Cambridge, Mass., is developing high-contrast displays based on electronic ink that can be printed onto paper and other flexible surfaces. That venture has already attracted such investors as Motorola and the Hearst Corp.

"The fundamental notion that you can print intelligent devices is quite appealing," says Russ Wilcox of E Ink. "Our goal is not just to bring one product or technology to market but also to create a research and development center at the forefront of display technology."

With product development under way, the company has made the signage market its initial target. That includes traffic warning signs, theater marquee displays, and in-store signs. In one pilot project, E Ink plans to provide a pharmacy chain with signs tied to the headquarters computer system so that printed prices and other data can be changed simultaneously in all or some of the chain's stores.

E Ink

A high-contrast electronic-ink display has sufficient flexibility to be curled around a pencil.

"We're taking advantage of the ability to produce displays that are naturally reflective and lightweight," Wilcox says. "If you had it on plastic, you could just unroll what you need."

That's still a long way from Jacobson's vision of an electronic book, which would integrate paper-thin, electronic-ink displays into a volume with roughly the heft and feel of a conventionally printed book.

One possibility is to have each page electrically linked to a chip-based display driver embedded in the bound book's spine. An external computer could then deliver text and other digital information to the driver, which would in turn send the appropriate signals to the electronic-ink dots on each sheet, in effect typesetting the pages.

Such pages could also be made responsive to a stylus so that a reader could resize the type, change the margins, and add notes. If it were possible to increase the rate at which microencapsulated particles switch from one state to the other, electronic-ink pages could also display animated images.

Adding a high-capacity data storage capability would turn an electronic book into a single-volume portable library. The user could call up any one of hundreds of books stored on an embedded memory card.

More than 500 years after Johannes Gutenberg completed the printing of the Bible, ink on paper remains an appealing, versatile, and cheap display technology. Jacobson and his coworkers are betting that paper coated with electronic ink can enhance the value and pleasure traditionally associated with reading a printed, bound book. ☐