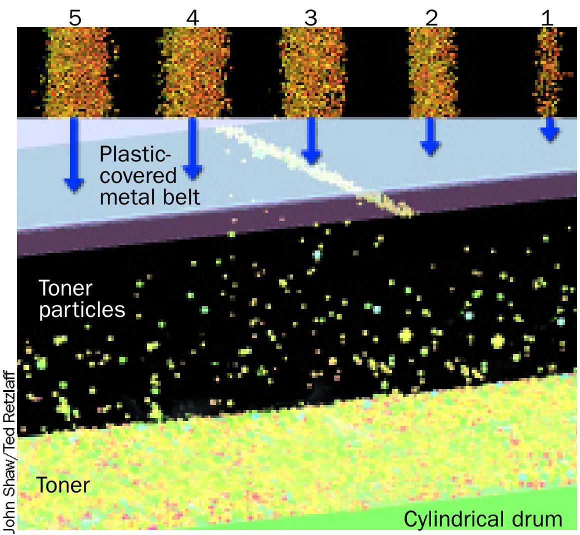
by Charles B. Duke and Dan Hays

The Cradle of Xerography

Physicists have played critical roles in the inception and evolution of xerography. Its invention by physicist Chester Carlson in 1938 represents one of the significant technology achievements of the 20th century. Although Carlson identified the basic requirements for xerography in his early work, the successful commercialization of the technology required significant subsystem and materials-engineering advances. Battelle Memorial Institute (Columbus, OH) made early innovations in the technology, but integrating the xerographic-process steps into a marketable product required the vision of the Haloid Corp., then a small photographic-paper company. Haloid acquired the rights to develop Carlson's invention and changed its name to Xerox Corp. in 1961.



John Shaw/Ted Retzlaff

In a laser printer, charged toner particles are transferred from the drum at the bottom to the belt at the top, on which the image of a line has been exposed by a laser. The line is uncharged and does not repel the particles, which build up around the line as it progresses from right (inset 1) to left (inset 5) until the charged particles repel any further development.

Although the first Xerox products were commercial successes, the scientific foundations of many xerographic-process steps and materials were poorly understood. Beginning in the 1960s, the company mounted major research efforts to advance photoreceptor materials; charging devices; developer materials; and development, fusing, and cleaning systems. These collective efforts have enabled Xerox to make an array of products that have served markets from desktop copiers to high-speed color publishing systems.

In the xerographic process, the requirements for the photoreceptor material are stringent. It must be an insulator in the dark and a conductor when exposed to light to form an electrostatic image. Early photoreceptors, which were expensive and mechanically rigid, were manufactured from chalcogenide glasses such as selenium and arsenic-selenium alloys. Developing a totally organic photoreceptor that was inexpensive, flexible, and panchromatic in its light-induced discharge characteristics was a great challenge.

In the mid-1970s, a two-layer photoreceptor structure was identified in which the function of generating the charges by light was separated from the function of transporting charges to discharge the photoreceptor. This proved essential to fabricating an efficient, long-lived organic photoreceptor consisting of a charge-generator layer coated with a charge-transport layer.

The charge-transport layer had to be transparent, a perfect insulator in the dark, and wear-resistant. Through an arduous effort, an organic molecule called di-meta-tolyl-diphenylbiphenyldiamine (TBD) was discovered which, when dispersed in a polycarbonate binder, met these requirements. Xerox has used the photoreceptor based on the TBD charge-transport layer in its copiers and printers since 1982, and this photoreceptor has enabled more than $100 billion in revenue since then. The American Chemical Society recently bestowed its Heroes of Chemistry 2000 award on Damodar Pai, Jack Yanus, and Milan Stolka of Xerox, the inventors of the TBD charge-transport layer.

After an electrostatic latent image is created on a photoreceptor, it is developed into a visible image by charged pigment particles (the toner), which are electrostatically attracted to the latent image. Designs for xerographic development systems have gone through several generations since the cascade development system used in the Xerox 914. In that copier model, only line copy and the edges of broad image areas were developed because in cascade development, toner is attracted to the photoreceptor only in areas of a strong electric field.

To improve image quality, Xerox introduced magnetic-brush development systems in the early 1970s. Polymer-coated magnetic carrier beads enabled the developer to be transported on a rotating roll containing stationary permanent magnets. Magnetic-brush systems with insulating carrier beads provide excellent development of image details, but they, too, are not efficient in developing broad image areas.

To understand this shortfall, Xerox scientists intensely studied the physics of two-component developer materials and magnetic-brush development systems during the 1970s and 1980s. They determined that the limitation on broad area development with a magnetic brush was due to a net carrier-bead charge caused by toner deposition onto the photoreceptor. Identifying this mechanism and constructing a corresponding broad-area development model provided new insights into critical material and process parameters.

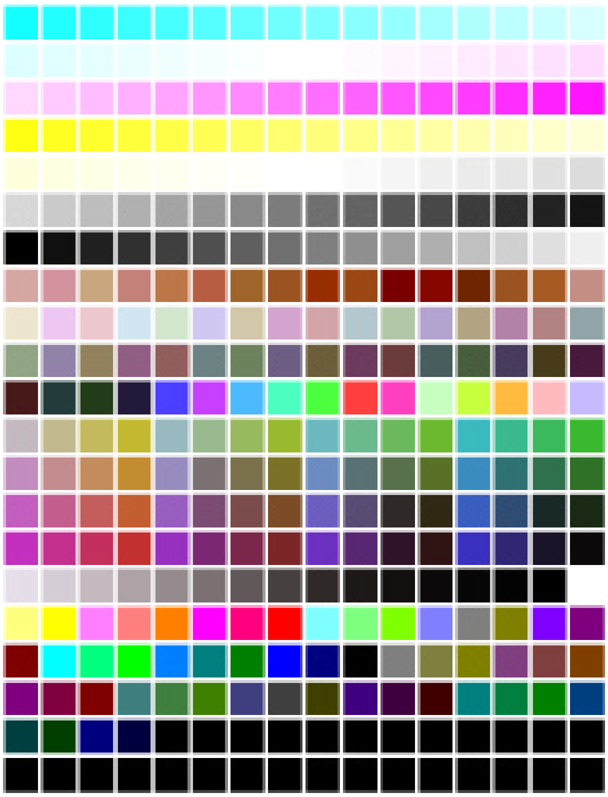
Ultimately, a new system design called highly agitated zone (HAZE) development was invented, which provided both excellent broad-area and image-detail development with hardware that was smaller and less expensive. This design was first incorporated into the Xerox 1065 Marathon copier, introduced in 1987, which made 62 copies a minute. The HAZE design was later incorporated into several other Xerox product platforms for copiers and printers. The combined revenue from all of the products embodying this development system accounted for nearly half of Xerox's total revenue in 1996. In recognition of the role of the HAZE development process in the success of three generations of Xerox's current products, Dan Hays, its inventor, received the 1997–1998 AIP Prize for Industrial Applications of Physics (see *The Industrial Physicist*, December 1997, p. 47).

Copying and printing high-quality, full-color images require extremely accurate (≤ 80 μm) positioning, or registration, of black with the secondary colors cyan, magenta, and yellow. Digital image processing enables high image quality through corrections to ensure registration of the image separations, the gray scale for toning, and other parameters. The images can be accumulated either on paper, an intermediate surface, or the photoreceptor. Each method has its advantages and disadvantages, so designing cost-effective xerographic copiers or printers that deliver high-quality color images is a challenging task.

In recent years, Xerox has directed its efforts toward full-color, high-speed xerographic printing. This requires more stringent uniformity of the color toner's deposition onto a photoreceptor than is needed for black-only printing, so Xerox had to create

WEB MATCH

Go to www.tipmagazine.com and click on "The Cradle of Xerography" under the heading "More TIP online." Compare the color target on your screen with the print version. Is it the same? Are the greens the same? The blues? The yellows? Probably not, and there are many reasons why not. Xerox researchers are using this target to develop a method for you to adjust your screen image so the colors do match. This will be demonstrated in an article in the June/July issue called "Color Documents in the Internet Era."



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new development-system designs. Physicist Jeff Folkins has been instrumental in identifying an advanced development-system design that produces a cloud of toner and meets the requirements.

Developing practical, low-noise development systems is a difficult task, which has benefited greatly from the construction of xerographic simulations suitable for use in engineering design. In these simulations, thousands of toner particles are moved under the influence of external fields and collisions with each other using Newton's equations. Generating these simulations required the proposal and validation of toner-toner and toner-photoreceptor force laws, and their use in an economically practical large-scale simulation code The result of a typical simulation, generated by physicist John Shaw and computer scientist Ted Retzlaff, is shown in the figure on p. 39.

With rapid advances in telecommunications, will a large demand for printed documents always exist? The answer is a resounding yes! Most information in the world is printed with offset printing presses that are most cost-effective for long print runs (>1000 impressions) with fixed images. Traditionally, most documents have been printed on an offset press, stored, and distributed according to need. On the other hand, digital printing with xerographic technology enables on-demand publications with variable images at high speeds.

Using telecommunication networks, one can distribute digital files where they are needed and print them in the exact quantity required. Such a capability, enabled by creating the document in digital form, distributing by telecommunications, and printing by xerographic technology, saves time, reduces cost, and eliminates document obsolescence, overruns, and warehousing.

BIOGRAPHY

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