M. H. Lee
J. E. Ayala
B. D. Grant
W. Imaino
A. Jaffe
M. R. Latta
S. L. Rice

# Technology Trends in Electrophotography

*Selected innovations and advances in electrophotographic printing are reviewed. Technological advances in photoreceptors, imaging techniques, toner development and cleaning, fusing, sensors, and new machine configurations and functions are discussed with respect to their possible applicability to future electrophotographic imaging systems. In general, improvements in print quality and reliability remain the main goals. In specific applications, added functions and an increased range of usable media are highly desired.*

## Introduction

As previous authors in this issue have indicated [1], electrophotography is an important technology base for non-impact line printers. Its significance will very likely increase as non-impact printing commands a greater share of the text and data processing business during the latter part of the decade. This paper attempts to point out some of the technological changes in the field that may accompany and perhaps ensure its continued strategic position during that period.

The electrophotographic process to produce printed output from digitized electronic information is shown schematically in **Figure 1**. The present analysis has been organized by analogy with the process as depicted. Technological developments in the following areas are described: 1) photoreceptors; 2) printer imaging techniques; 3) toner development; 4) cleaning; 5) fusing; 6) sensors; and finally 7) new machine configurations and functions.

In this review we address selected technology developments that have occurred in these areas. We do not attempt to be comprehensive from either a historical or process perspective but rather highlight those changes that we believe to be of greatest import to future printer applications of electrophotography. In many areas no particular trend dominates. A technological option may have a competitive advantage in one application but not in another. This is a natural result of the immense flexibility of electrophotography where, for example, print speed varies by more than an order of magnitude between high- and low-end systems. Aside from the imaging section, the printer has many components in common with the copier. Thus copier advances are occasionally cited to illustrate corresponding trends in printers. Some related processes are omitted from present consideration (e.g., charging system, document finishing), and the reader is referred to excellent sources for a more comprehensive review of these subjects [2–7]. In addition, the discussion is restricted to the electrophotographic imaging process, which means in particular electrostatic charge image development from a photoreceptor surface.

## 1. Photoreceptors

Photoreceptor materials may be the most active publication and patent area in electrophotography, generating hundreds of abstract citations every month. A possible explanation for this activity is the extremely challenging set of properties that the photoreceptor must exhibit. In operation it must sustain high voltages in the dark and discharge rapidly upon exposure to radiation. For this process to proceed efficiently, the mate-

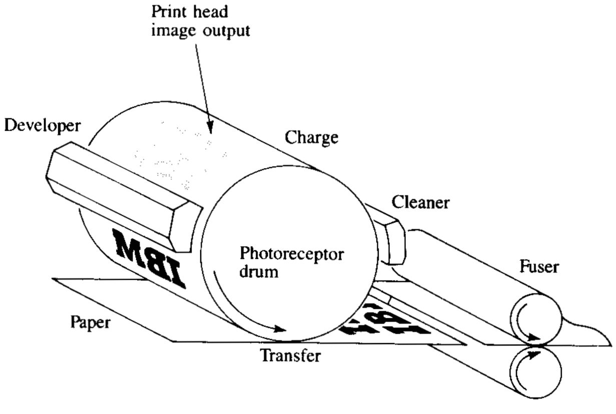


**Figure 1** Electrophotographic process.

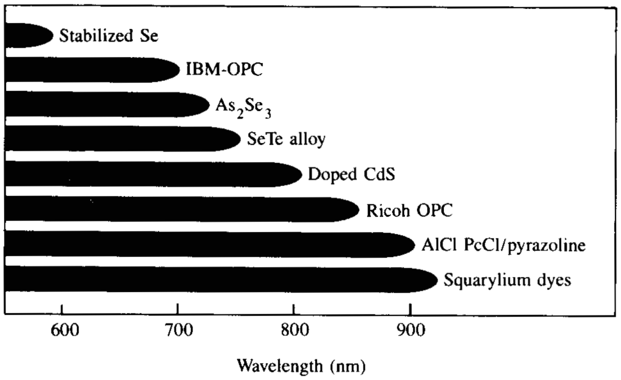


**Figure 2** Relative spectral sensitivities of several photoconductors.

rial should have high photosensitivity in the wavelength region appropriate for the specific imaging technology, high charge mobility, and satisfactory electrical properties such as low dark decay and minimal fatigue. It should be durable, nonhazardous, and readily manufactured in high yield. Since no one system displays superior properties in all of these categories, photoreceptor design and selection must address the overall requirements of the particular application. One result is the extreme diversity of photoreceptor materials employed today.

Most photoreceptor systems can be placed in one of three general categories: inorganics, inorganics in an organic binder, and organics. The first constitutes the most common type and includes such materials as Se and $As_2Se_3$. They are known for their toughness and durability, highly desirable properties for reliable performance. The second consists of such systems as ZnO or CdS suspended in a polymer matrix. The third, organic photoreceptors, is continuing to find more frequent usage despite being generally less durable than inorganics. They are typically composed of molecular dyes in a polymeric matrix, fabricated in either single-layer or double-layer configurations. Most recent studies have focused on two-layer systems, which offer the prospect of improved performance since the charge generation (photosensitivity and wavelength sensitivity) and charge transport properties of the system can be optimized independently [8]. These are considerable improvements over the first two-layer systems consisting of Se on an organic layer [9]. A noteworthy exception to this trend is the single-layer Kodak aggregate photoconductors reportedly capable of functioning similarly from either positive or negative charging [10].

The emergence of semiconductor diode laser print heads operating in the near infrared (Section 2) has dictated the need for new photoreceptors with long wavelength sensitivity. The search has centered around two technical approaches: 1) "tuning" the spectral response of existing photoconductors through alloying and 2) designing totally new materials. The advantages of organic photoconductors in this task are clear. Inorganics are generally limited to alloying to move the peak response of the base material from the blue or green. Several investigators have reported some success in red shifting selenium [11, 12], cadmium selenide [13], and arsenic triselenide [14] by addition of tellurium. Organics, on the other hand, are not bound by such a restriction and can be designed systematically from well-understood principles. As a result, a much greater variety of infrared sensitive photoreceptors is coming from new organic dye systems. These typically have a spectral response peaked near the laser wavelength. Examples are the new Ricoh azo-based charge generation material [15], the IBM [16], Xerox [17], and Pitney Bowes [18] work on squarylium dye systems, and the Kodak trimethine thiopyrylium dye [19]. Novel organometallic photoreceptor systems have also been described [20–22]. These include photoconductivity in the near-infrared from sublimed chloroaluminum phthalocyanine chloride [20] and a description of a complete two-layer infrared photoreceptor consisting of $\varepsilon$-type copper phthalocyanine as the charge generation material [21]. The sensitivity ranges of some of these materials are shown in **Figure 2.**

A photoreceptor development that may hold the most significance for the future is the activity in hydrogenated amorphous silicon (a-Si:H) [23–26], a material produced by the RF glow discharge composition of $SiH_4$. The reported advantages of this nonhazardous system include excellent photosensitivity and broad spectral sensitivity (450–750 nm), high surface hardness, mechanical strength, flexibility, and thermal stability. An additional attraction of this system is the strong existing technical base in silicon, and more recently, amorphous silicon materials from the semiconductor field. Areas in which further investigations will undoubtedly be directed include manufacturability, improved electrical properties, and infrared sensitivity enhancements.

Beyond these areas of current photoreceptor research, several directions emerge as desirable for long-term research activity. A major breakthrough in the formulation of long-lived photoreceptor materials, tolerant of large variations in image development, transfer, and cleaning processes, would represent significant machine reliability and cost improvements. Secondly, despite the established advantages of multiple-layer photoreceptor systems noted above, a high-performance single-layer organic photoreceptor system is desirable from the viewpoint of manufacturability. Finally, a number of publications and patents describe extremely sophisticated photoreceptor configurations designed specifically for color electrophotography [27–29]. For example, Ricoh has demonstrated two-color electrophotography [29] employing a complex four-layer photoreceptor in which the two photoconductive layers exhibit distinct wavelength responses. As business requirements for color copying and printing increase, we can expect to see additional requirements of this type placed upon the design of photoreceptor systems for the future.

## 2. Printer imaging techniques

The most common techniques for image/character generation for electrophotographic printers are based on some form of raster addressing. Early systems used cathode ray tubes (CRTs) for this purpose. These generally had poor throughput because of insufficient phosphor brightness and inefficient lens coupling to the photoconductor. The introduction of the fused fiber optic faceplate (FO CRT) [30] increased the available intensity on the photoconductor by thirty times. Nevertheless, the technique remains competitive only at the low end [2]. Little improvement beyond this may be realized, since both the CRT and the fused fiber faceplates are mature technologies.

An alternative technology at the low end and above is the $GaAs_{1-x}P_x$ light-emitting diode (LED) array. Various configurations have been proposed [31], but most consist of a stitched row of linear arrays to form one entire print line. The design can be quite compact because it does not need a separate scanning system. Digitized information is fed in parallel to the diodes, which turn on and off with the speed of the driving circuit. This feature suggests the prospect of high-end printing rates, but such an extension would require some improvement in photoreceptors. Secondary concerns about the device have not been entirely removed. These center on the constancy of light output over the entire array, the registration of adjoining subelements within the print line, lifetime, and cost. Despite these uncertainties, rapid progress can be expected. A major contribution to its emergence has been the development of gradient index lens arrays which, unlike the FO CRTs, leave ample space between the array and the photoconductor [32]. The diode array should stay ahead of potential rival, parallel input technologies such as the magneto-optic light switching array [33] and the smectic liquid crystal light valve [34] because of the large existing technology base in III-V light emitters. The twisted-nematic liquid crystal array uses a much more mature technology and could become quite competitive at the very low end.

At the high end scanning laser systems have dominated. The sources in commercial machines are typically low-to-moderate-power, continuous-wave (CW) He-Ne [35–40] or He-Cd [41] gas lasers chosen to match the spectral characteristics of the photoconductor. Although the gas lasers have worked well in these applications, $Ga_{1-x}Al_xAs$ diode lasers (generally called GaAs lasers) are becoming attractive alternatives [42, 43]. The power-efficient laser diode can be current-modulated, and its transistor-can size is ideal in the space-efficient machines. This compares with a relatively large, inefficient CW gas laser which needs an acousto-optic modulator to digitize the beam. At present, the diode laser has seen limited usage [44] for several reasons. The output wavelength (780–820 nm) is longer than the useful spectral sensitivity range of commonly employed photoconductors. Stable, high-power, long-lived diodes had not been commercially available at reasonable cost. Finally, the output power had been limited to around that of a medium-power He-Ne gas laser (10 mW). These problems have largely been solved. Perhaps the most important breakthrough is in the output power of diode lasers. Innovations in the diode structure have enabled the maximum output to increase to above 50 mW [45], and such devices are becoming commercially available. In the laboratory laser diode arrays have completely removed the power limit [46]. Output above 1.5 W at a single point has been attained by utilizing the phase-locked emission from multiple beams on a single chip [47]. This represents an order of magnitude increase over the power available in even the latest commercial diode lasers, and improvements will surely follow. Tight focusing in the array configuration has also been demonstrated [48]. These factors suggest that the emergence of diode lasers at the high end should occur soon.

The laser systems need well-designed optics to place a focused beam (typically 150 to 200 $\mu$m across at $1/e^2$ intensity) on the photoconductor surface. Several He-Ne laser scanning systems [35–40] have utilized an acousto-optical device for beam modulation, a rotating polygonal mirror for beam scanning, and various optical systems for beam shaping. The last function presents several interesting and difficult engineering problems. In the IBM 3800 laser printer, for example, the optical system incorporates an optimized $f/\theta$ lens system to ensure scan linearity and constant spot size for all points in the field. An innovative anamorphic optical correction system is used to provide constant scan-to-scan spacing and scan straightness [35]. This correction system and a scan start detector together allow the use of very moderate optical tolerances on the rotating polygonal mirror. Other systems have employed linear clocking gratings and alternative correction systems to achieve comparable performance [38, 49].

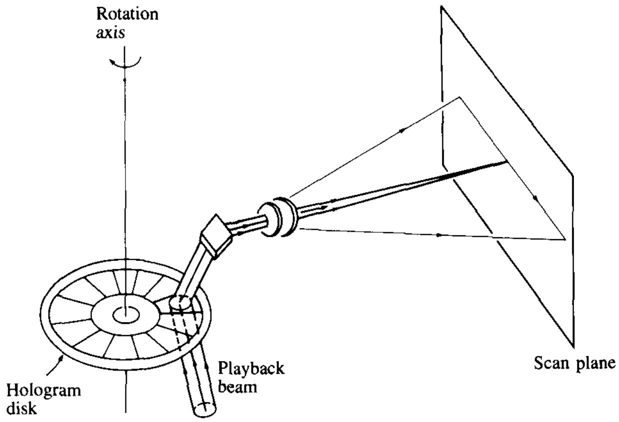


**Figure 3** Holographic scanner. After Ref. [54].

Holographic scanning is an alternative technology which may become a significant factor in future print heads [50–52]. Originally envisioned as a cost reduced replacement for polygonal mirrors, holographic scanning also has the potential for added function by virtue of its inherent lensing capabilities [53]. It is currently in point-of-sale systems [54] as well as non-impact printers [55] and may find increasing use in electrophotographic systems as further improvements are made in low-cost replication processes. **Figure 3** shows the inherent simplicity of a holographic scanner [54].

Galvanometer scanning has been considered in some electrophotographic systems with modest performance requirements. This form of scanning has been limited to the low end, as in one experimental system operating at 13 pages/min which used acousto-optic deflection and modulation to vertically sweep out a character while horizontally scanning using the galvanometer [56]. Recently introduced induction drive galvanometer scanning may improve the deflection angle/scan rate by the use of a symmetrical design operating at resonance [57].

As a component in an electrophotographic printer, the print head is probably the most reliable and well-engineered. Improvements will primarily be directed at cost reduction, more compact packaging, and manufacturability. These may include plastic optical components and simplification of existing technologies rather than the development of new ones [58]. To a lesser extent, added function in the form of higher resolution and/or gray scale will be important. The diode laser will likely be the primary light source in the high end and mid-range. The LED array should be the top candidate in the low end and may be viable beyond. Competition between holographic, galvanometer, and polygonal mirror scanning technologies should continue, with each having some specific cost and performance advantages in particular applications.

## 3. Development

In some ways toner development is the most complex step in the electrophotographic process. Competition among electric, magnetic, and van der Waals forces dictates whether toner adheres to or is removed from the photoconductor surface and thus controls the fidelity of the developed image. The process is sensitive to the details of the hardware and materials involved, which accounts for the considerable effort directed toward its improvement and understanding [2–7].

Xerography [7] is by far the most dominant, established development technology. In this dry process the development mix may consist of one (mono) component, toner, or two (dual) components, carrier beads and toner. In dual-component technology the beads serve two functions: they impart a charge to the toner and transport the latter to the vicinity of the electrostatic image. Early dual-component systems employed cascade development. These had a number of problems, among which was poor solid area fill with optical density (OD) $< 1.0$. Present technology uses multiple magnetic rolls and partially conducting mixes with an iron or steel carrier to form a magnetic brush. Solid area fill has improved dramatically with OD $> 1.3$. In high-end applications dual-component development is used exclusively. The method provides rapid, high-quality output rivaling offset printing at reasonably low toner cost. Recent advances in the understanding of dual-component development [59–64] have paved the way for the improved output quality of today's machines. Despite its popularity, the technology is not without some drawbacks. The mix ratio must be actively controlled for consistent output. The triboelectric characteristics of the carrier coatings change with use. The developer must be large enough to contain both the toner particles and the much larger carrier beads. Modifications to the usual dual-component process include the microtoning system pioneered by Minolta, which uses a much smaller carrier. The system produces good print quality in a smaller developer volume, but it has not been extended much beyond the low end [4].

A conceptually straightforward simplification of two-component development is the magnetic monocomponent technology. By incorporating magnetic material into the toner, the magnetic brush can still be used to deliver the toner to the photoconductor [65, 66]. The toner acquires charge by induction and triboelectrification with the developer. The hardware is simpler and more compact, and copy quality can be good with OD around 1.3 for line copy and 1.1–1.2 for solid areas. The complexity is actually moved to the toner, which is subject to the additional magnetic interaction. Recent measurements of interparticle forces [67], $q/m$ ratio [68], and charge transport [69, 70] and calculations of the magnetic forces [71] have clarified some aspects of the process. More must be done to understand its humidity sensitivity and limitations on speed and copy quality. Canon has used magnetic component toner in its projection technology [66]. This noncontact development process is based on toner jumping a 300-$\mu$m gap between the developer and the photoreceptor in an ac electric field.

An alternative single-component technology called touchdown or impression development uses nonmagnetic toner [72–75]. A schematic of the process is shown in **Figure 4.** As in dual-component, the developer mechanism charges the toner by triboelectrification and transports it to the photoconductor. Early prototypes made very good copies, especially in reproducing originals with much gray scale [75], but suffered from toner filming on the developer roll which altered the charging characteristics. Xerox recently devised a modification to the scheme [76] which addresses this problem. Charging is accomplished by injection from an electrode which contacts the toner layer. This process appears to have the advantage of controlling the toner charge without attempting to maintain the long-term triboelectric properties of the developer. The electrode can be used to control the background instead if toner filming is otherwise eliminated [77]. The simplicity of the impression development hardware and the toner formulation compared to magnetic monocomponent technology makes the process attractive if the associated problems can be solved.

In liquid development [78] the toner is charged and transported through interaction with the suspending fluid. The process also requires simple hardware, since no mechanical transport device is needed and no fusing is necessary. It has the highest resolution capability for an electrophotographic process because much finer toner particles can be used in liquid. Its principal drawback is solvent retained in the output which is subsequently released into the environment. Some recent innovations have addressed this problem. Canon patented the "Liquid-Dry" toning process, which uses a special sponge-rubber-covered developer roll [79]. The roll presses against the photoconductor in the development zone. Downstream the rubber relaxes and sucks excess liquid into its interior. In a process patented by Landa [80, 81], absorption in the paper is minimized by reducing paper contact with the carrier fluid, using spacers added to the toner and controlled protuberances on the photoreceptor.

## 4. Cleaning

A necessary condition for high print quality is effective cleaning. The simplest method is to scrape the photoconductor with a blade. In liquid toning this is the only possible technique because of the high capillary force holding the toner to the photoconductor [82]. In low-end xerographic applications, a metal or polymeric blade cleaner is ideal. It is simple, inexpensive, and very compact. The cleaning mechanics has been carefully studied [82].

If usage is high, the blade and the photoconductor wear and must be changed more frequently, increasing user frustration

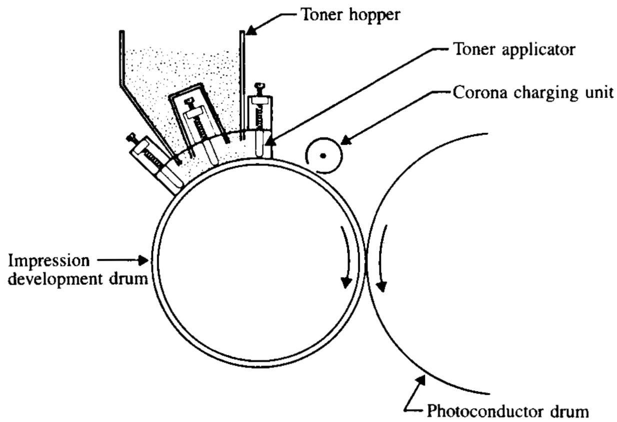


**Figure 4** Impression development process.

and maintenance cost. Thus at the mid-range and above, magnetic brush cleaners and mechanical brush with vacuum assist are most common. At the high end mechanical brushes are generally used. This cleaning process has been analyzed and its intricacies understood [83]. Xerox recently introduced in their high-end 1075 copier a magnetic cleaner similar in principle to the developer. Although magnetic cleaners had been used in machines with monocomponent technology, this was the first for dual-component. The cleaner is much quieter and more compact than fiber brush with vacuum and should handle the cleaning with less wear. But, like development, the physics of magnetic brush may be quite complicated.

## 5. Fusing

The toner image transferred to paper from the photoconductor must be permanently bonded or fused by inducing the powder to coalesce with itself and adhere to the substrate [84]. The toner should be sufficiently malleable to fuse but not agglomerate in the agitating developer or film significantly on the photoconductor. Most common materials having these characteristics are based on thermal plastic resins. They can be fused using wicked and dry hot roll, radiant heat, flash, chemical vapor, or cold pressure.

In the most prevalent technology, hot roll fusing, toned paper passes between a pair of rotating rollers, at least one of which is heated. The heat melts the toner and roller pressure pushes it into the paper. Although the technique is straightforward, care must be exercised to prevent the toner from sticking to the roller and consequently creating an offset or ghost image on the next sheet of paper. The problem can be addressed by either using a special oil wicked onto the surface of the roll [85, 86] or choosing the roll material to have the desired release properties, as in the IBM Series III, 6670, and 3800 [87, 88]. Toner can be fused without heat by supplying sufficient pressure between a pair of metal rollers. Although cold pressure fusing requires very little energy, it has not been widely accepted because of some print quality drawbacks. Foremost is the glossy appearance of the print and the background paper from the high compression. This has led to innovations in textured coatings on the roll to simulate the appearance of hot roll fused copy [89].

Hot roll and cold pressure require physical contact between the substrate and the roller, and thus these approaches limit the range of media that the machine can handle. This has sparked interest in reviving and improving older noncontact methods. The Hewlett-Packard 2680 Laser Page Printer [90] uses a two-stage system. The toned paper is first heated conductively as it passes over a hot platen. Final fusing is accomplished by radiant heat transfer from a quartz halogen lamp. The hot platen ensures that the paper is warm even though it absorbs little lamp radiation compared to the toner during the second stage. A serious safety problem with radiant heating in the past has been the ignition of paper when jams occur. This deficiency has largely been eliminated by advances in paper sensing and control techniques [91]. Siemens recently introduced a laser printer with a chemical fusing technology similar to some of the first electrophotographic systems. In operation the paper web passes through a vapor which melts the toner. The principal concern with this technique is similar to that in liquid development: absorption of solvent chemical into the substrate and its subsequent evolution. This has apparently been overcome by clever engineering [92]. Another noncontact method is flash fusing, which uses short pulses from a high-power lamp [93] to deliver radiant energy to the toner. High hardware cost has limited this method to high-end applications.

One important consideration in selecting the fuser technology is its effect on paper properties. In roll-type fusing the pressure deforms the paper fibers, leading to changes in the paper dimensions and surface smoothness. Heat drives off the natural moisture. These factors cause many reliability problems in the paper path through the fuser and into the subsequent output or duplexing operation. In the usual approach, paper transport is managed by a judicious combination of hard rolls and those with uniform deformable coatings [94]. An interesting alternative is found in the Kodak Ektaprint 250 duplicator, which introduced automatic single-pass duplex copying. In this machine the toned image is transferred to both sides of the paper before it goes through the fuser. The station consists of two wicked hot rolls, each of which is covered with a sophisticated multiple-layer material to fuse the toner on both sides simultaneously without smearing or offsetting the powder [95, 96].

Future fusing technologies must address the increasing need to expand the set of substrates used in electrophotography to include such items as preprinted forms, envelopes, and gummed labels. This should stimulate activity in noncontact fusing techniques since present contact methods are inadequate. Preprinted forms, for example, can offset their inks to roll-type fusers which then attract toner and subsequently cause reliability problems. The prime candidates for these applications, radiant, chemical vapor, and flash fusing, are not without their drawbacks. It must be shown that the chosen techniques do not release objectionable vapors from the ink in the preprinted form or from the glue in the gummed label. In addition, reliability and safety will have to be explored and proven before the technologies will be widely accepted.

## 6. Sensors

Consistent output quality from an electrophotographic engine requires the maintenance of the proper operating parameters against drifts in machine parameters and external conditions. This means close monitoring of the process and adjusting for deviations. With the present widespread use of microprocessors such control is routine [97, 98] if adequate sensors are available. Consider dual-component development. The image density depends on the toner-carrier ratio, which changes as the toner is used. To maintain a reasonable mix, the process can be monitored using the reflectivity of a test patch imprinted on the edge of the paper [49, 99–101] or a test image on the photoconductor itself [102]. Measuring the toner reflectivity on the paper is simple and reliable. The sensor package can be a single inexpensive assembly [49] that includes a light source, typically a LED, and a photodetector. Reflectivity from the photoconductor gives a more direct indication of the developer condition. This may potentially lead to somewhat better control if intermediate steps such as transfer can be monitored as well. But the technique requires shielding from toner dust around the developer, which can result in a complicated design [102]. Parameters within the developer can also be measured, including mix characteristics such as the magnetic permeability, dielectric permittivity, and triboelectric properties [103] and the reflectivity of the magnetic brush [104]. These methods, however, give results that are several steps removed from the desired information, the image quality on the paper.

Proper toner placement on the paper requires accurate determination of the relative positions of the photoreceptor panel and the paper. The Kodak Ektaprint 250, with its automatic single-pass duplex copying, has a sensing network capable of tracking several pieces of paper at one time [95]. In the duplex mode the paper with toner on one side must be flipped and moved to the duplex transfer position within much less than a second. As in most machines, the paper location is determined by the change in reflectance from the surface or transmission across a gap [95, 98]. In either case the technique again involves a light source and a photodector which may be incorporated with the optics into a single package [49]. This combination should remain dominant relative to other noncontact position sensors [105, 106] because it works well and the hardware, including the supporting electronics, is inexpensive. Microswitches are cost-effective in restricted applications.

The sensor requirement of a fuser system depends on its mode of operation. For hot roll fusers, the incoming paper must be in the proper position because heat flow, and hence print quality, is sensitive to the exact roller-paper configuration. The paper position near the fuser is determined as above [107] and adjusted by a difference in pressure applied between the two rolls at the two ends [107, 108]. The fuser rolls are usually heated and controlled in several sections. Temperatures in general are determined by thermocouples or precision thermistors [90, 109]. These are not likely to be replaced by temperature sensors using rare earths [110], III-V semiconductors [110], silicon [111], or other techniques unless one of the latter is needed in an alternative fusing technology

The number of sensors in present high-end electrophotographic printers and copiers is quite large. The Siemens ND 2 laser printer, for example, has more than 70 sensors [49]. More will be installed in the future to improve machine performance and dependability. Already they measure such seemingly second-order parameters as the mix volume in dual-component developers [94] and the toner dusting [49]. Additional position sensors may be used to keep track of the paper for better registration and to detect jams. Other sensors will be introduced to monitor parameters which affect the process but are not currently measured. The humidity dependence of monocomponent development may be reduced with compact ceramic [112] or polymeric capacitive [113] humidity sensors. The sensitivity of the electrophotographic process to paper properties can be neutralized if the proper parameter set can be defined and monitored.

## 7. New machine configurations and functions

Microelectroelectronics has not only simplified control of the electrophotographic process as noted above, but changed the machines in many other ways as well. One major innovation area is in customer convenience features. The Kodak Ektaprint 250 has been highlighted as a "plain talk" duplicator [114] which communicates in normal language messages on the status of machine readiness and maintenance requirements. The operator employs an electronic touchpad and the machine features both visual and audio response. The "talking" copier has been described in a recent Xerox patent [115]. A comparison of the Kodak Ektaprint 250 [95] and its predecessors, the 100 and 150 [116], reveals the trend in increased machine computational power. As a copier the 250 basically controls just the electrophotographic process. Nevertheless, it has three microprocessors with more than 120K bytes of memory which allows the operator to independently control the exposure intensity, the photoconductor charge potential, and the developer roller potential to optimize the copy quality. It can display more than 400 messages. The predecessors have an order of magnitude less memory and a correspondingly smaller message set.

Reliability remains a critical area of concern for the electrophotographic process. The evolving trend, aside from better process control, is to reduce the annoyance associated with machine repair. Self-diagnostic routines which periodically check machine performance are becoming increasingly prevalent. If self-adjustments cannot be made, CRT or LCD displays may pictorially identify for the user the location of machine problems such as paper jams. Repairs are also facilitated by such aids as the electronic system log of the operating parameters on the HP2680, which can help isolate irregularities from intermittent failures [98]. In general the goal is to provide sufficient internal diagnostics to maintain high-quality output and eliminate service calls when possible. Innovative examples of this philosophy are the recent Canon mini-copiers, PC-10 and PC-20 [117]. This product series introduces a totally new approach to machine maintenance by incorporating key consumable components into a convenient user-replaceable cartridge system. While this technique is unlikely to find direct applicability in higher-speed and greater-volume machines of the future, the underlying philosophy of this design will undoubtedly have impact.

Document formatting is becoming more flexible with the introduction of all-points-addressable printers such as the HP 2680 and the IBM 3800 Model 3 [40], the latter at 20 040 line/min (12 line/in.) with 240-dot/in. resolution. Such systems typically have a large number of available fonts printable anywhere on the page. The HP printer has a custom bipolar bit slice processor to achieve its 45-page/min speed [118]. A different approach is used in systems like the 8086 microprocessor-based IBM SHERPA attachment to the IBM 6670 Information Distributor. In this case every point on a page up to legal size at 240 dot/in. is placed in memory before printing begins. The system excels in graphics while retaining the complete text processing capabilities of other all-points-addressable machines. The page bit map and font overhead require a 1M-byte memory, considerably more than other methods. Its microprocessor approach is also slow despite direct memory access to match the speed of the 6670 engine. Nevertheless, with the advent of 32-bit microprocessors at higher clock rates and decreasing memory cost, SHERPA-type systems could also become competitive at the mid-range and beyond.

The traditional boundary between electrophotographic copiers and printers has become blurred as machines such as the IBM 6670 [119] are introduced which perform both functions. Technological innovations continue to expand the combinations of function offered. An excellent example is the Fujitsu Copier Printer Scanner [120], which incorporated document

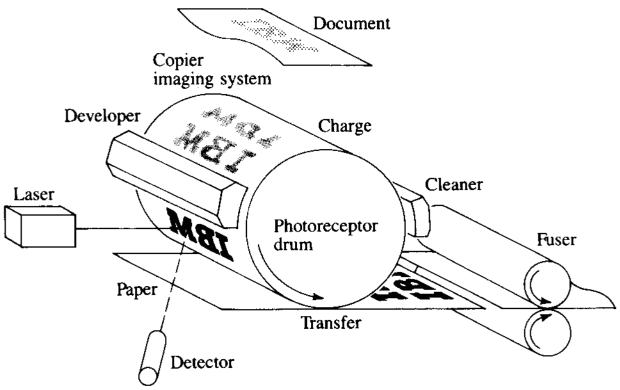


**Figure 5** Laser printer scanner.

scanning for facsimile purposes by attaching a CCD to a printer/copier. In an alternative approach, we have recently demonstrated the integration of document scanning directly into the electrophotographic process (**Figure 5**) [121]. The document is first imaged onto the photoconductor and toned in the usual fashion. The image is then scanned with the print laser; the reflected signal is captured and stored electronically for subsequent facsimile transmission. The normal electrophotographic printer/copier engine thus has scanning capability with only minor modification and can operate in a facsimile mode at the process speed and image quality inherent in that engine.

An equally significant development of advanced function for electrophotography is color copying and printing. Full-color capability from three-cycle image development has been available for some time in the Xerox 6500 [122] and more recently from Canon [123]. A significant number of technical innovations specifically directed toward color imaging (both two-color and full) have been recently described. Among these are the sophisticated photoreceptor designs of Kodak [27] and Ricoh [29], which provide full- and two-color image capability, respectively (Section 1). Both systems employ complicated multilayer organic photoreceptors in which selective absorption has been provided by the appropriate choice of charge generation materials. These clever implementations are both an excellent indication of the exciting possibilities and the significant complexity awaiting color engines of the future.

## References and note


1. R. A. Myers and J. C. Tamulis, "Introduction to Topical Issue on Non-Impact Printing Technologies," *IBM J. Res. Develop.* **28,** 234–240 (1984, this issue).
2. M. M. Shahin, "Future Developments in Electrophotography for Non-Impact Printing Applications," *Proc. 1st Int. Cong. Adv. Non-Impact Print. Techn.,* Venice, 1981, pp. 1350–1379.
3. E. S. Baltazzi, "Recent Trends in Electrophotography and its Applications," *J. Appl. Photogr. Eng.* **8,** 224–226 (1982).
4. E. S. Baltazzi, "Recent Development in Electrophotographic Processes, Materials, and Related Fields," *J. Appl. Photogr. Eng.* **6,** 147–152 (1980).





5. D. Winkelmann, "Recent Developments in Electrophotography in Europe," *J. Appl. Photogr. Eng.* **4,** 187–194 (1978).
6. R. M. Schaffert, "Electrophotography Yesterday, Today, and Tomorrow," *Photogr. Sci. Eng.* **22,** 149–153 (1978).
7. R. M. Schaffert, *Electrophotography,* Rev. Ed., John Wiley & Sons, Inc., New York, 1975.
8. P. J. Melz, R. B. Champ, L. S. Chang, G. S. Keller, L. C. Liclican, R. R. Neiman, M. D. Shattuck, and W. J. Weiche, "Use of Pyrazoline-Based Carrier Transport Layers in Layered Photoconductor Systems for Electrophotography," *Photogr. Sci. Eng.* **21,** 73–78 (1977).
9. P. J. Regensburger, "Optical Sensitization of Charge Carrier Transport in Poly(n-Vinyl Carbazole)," *Photochem. Photobiol.* **8,** 429–440 (1968).
10. W. J. Dulmage, W. A. Light, S. J. Marino, C. D. Salzberg, D. L. Smith, and W. J. Staudenmayer, "An Aggregate Organic Photoconductor. I. Chemical Composition, Preparation, Physical Structure, and Optical Properties," *J. Appl. Phys.* **49,** 5543–5554 (1978).
11. L. Cheung, G. M. Foley, P. Fournia, and B. Springett, "Selenium Tellurium Alloys as Photoconductor," *Photogr. Sci. Eng.* **26,** 245–249 (1982).
12. A. Melnyk, "An Infrared Sensitive Photoreceptor," Society of Photographic Scientists and Engineers (SPSE), Rochester, NY, May 1982.
13. S. Faria, "Infrared Photoconductor For Electrophotography of a Copper Activated Mercury Containing Cadmium Selenide Telluride," U.S. Patent 4,374,917, 1983.
14. M. Lutz and B. Reimer, "IR-Sensitive Photoreceptor for Laser Recording," SPSE, Rochester, NY, May 1982.
15. S. Arora and W. Murphy, "Red Sensitive Photoreceptors for Laser Printers," SPSE, Rochester, NY, May 1982.
16. R. B. Champ and M. D. Shattuck, "Sensitive Electrophotographic Plates," U.S. Patent 3,824,099, 1974.
17. R. O. Loutfy, C. K. Hsiao, and P. M. Kazmaier, "Photoconductivity of Organic Particle Dispersions: Squaraine Dyes," *Photogr. Sci. Eng.* **27,** 5–9 (1983).
18. M. Chang and P. Edelman, "Squarylium Dye and Diane Blue Dye Charge Generating Layer Mixture For Electrophotographic Light Sensitive Elements and Processes," U.S. Patent 4,353,971, 1982.
19. S. P. Clark, G. A. Reynolds, and J. H. Perlstein, "Infrared Sensitive Photoconductive Composition, Elements and Imaging Method Using Trimethine Thiopyrylium Dye," U.S. Patent 4,327,169, 1982.
20. K. Arishima, H. Hiratsuka, A. Tate, and T. Okada, "Electrophotographic Photoreceptor with High Sensitivity in the Near-Infrared Region," *Appl. Phys. Lett.* **40,** 279–281 (1982).
21. A. Kakuta and Y. Mori, "Near Infrared Sensitive Organic Photoreceptors," SPSE, San Francisco, June 1983.
22. S. Grammatica and J. Mort, "Infrared Sensitive Organic Photoconductor," *Appl. Phys. Lett.* **38,** 445–446 (1981).
23. I. Shimizu and T. Komatsu, "a-Si Thin Film as a Photoreceptor for Electrophotography," *J. Non-Crystal. Solids* **35,** 773–778 (1980).
24. K. Wakita, Y. Nakayama, and T. Kawamura, "Preparation and Properties of GD a-Si:H Films for Electrophotography," *Photogr. Sci. Eng.* **26,** 183–187 (1982).
25. Y. Nakayama, A. Sugimura, M. Nakano, and T. Kawamura, "A New a-Si:H Photoreceptor Drum: Preparation, Electrophotographic Properties and Application," *Photogr. Sci. Eng.* **26,** 188–193 (1982).
26. E. Inoue and I. Shimizu, "Design of a-Si Photoreceptor for Electrophotography," *Photogr. Sci. Eng.* **26,** 148–152 (1982).
27. T. M. Plutchak, "Color Electrophotography using a Photoconductive Layer on Both Sides of a Multicolor Screen," U.S. Patent 3,836,363, 1974.
28. J. H. Dessauer, "Color Xerography," U.S. Patent 2,962,374, 1960.
29. T. Ishida, T. Satoh, M. Yoshikawa, and S. Karasawa, "Two Color Electrophotography. II. Photoreceptor," SPSE, Washington, 1981.

30. J. E. Wurtz, "Fiber Optic CRT's and Their Use in Copy Machines for Plain-Paper Non-Impact Printing," *J. Appl. Photogr. Eng.* **6,** 73–77 (1980).
31. K. Tateishi and Y. Hoshino, "Electrophotographic Printer Using LED Array," *IEEE Trans. Indust. Appl.* **IA-19,** 169–173 (1983).
32. D. T. Moore, "Gradient-Index Optics: A Review," *Appl. Opt.* **19,** 1035–1038 (1980).
33. B. Hill and K. Schmidt, "Fast Switchable Magneto-Optic Memory Display Components," *Philips J. Res.* **33,** 211–225 (1978).
34. S. W. Depp, J. M. Eldridge, A. K. Juliana, and M. H. Lee, "Smectic Liquid Crystal Light Valve for Printhead," *IBM Tech. Disclosure Bull.* **25-12,** 6325 (1983).
35. J. M. Fleischer, M. R. Latta, and M. E. Rabedeau, "Laser-Optical System of the IBM 3800 Printer," *IBM J. Res. Develop.* **21,** 479–483 (1977).
36. J. R. Lewis and L. M. Hubby, "Optical System Design for the Laser Printing System," *Hewlett-Packard J.* **33-7,** 3–10 (1982).
37. G. K. Starkweather, "High Speed Laser Printing System," *Laser Appl.* **4,** 125–189 (1980).
38. D. E. Grant, "Optical-Mechanical Design of the IBM 6670 Laser Printhead," *Proc. SPIE* **200,** Paper 25 (1979).
39. W. Meye, "Optical Character Generation for a High Speed Non-Impact Printer," *J. Photogr. Sci.* **25,** 183–186 (1977).
40. David McMurtry, Mike Tinghitella, and Roger Svendsen, "Technology of the IBM 3800 Printing Subsystem Model 3," *IBM J. Res. Develop.* **28,** 257–262 (1984, this issue).
41. I. Kondo, T. Musada, and M. Horie, "High-Speed Laser Printer," *Fujitsu Sci. Tech. J.* **16,** 39–55 (1980).
42. T. Kajimura, T. Kuroda, S. Yamashita, M. Nakamura, and J. Umeda, "Transverse-Mode Stabilized $Ga_{1-x}Al_xAs$ Visible Diode Lasers," *Appl. Opt.* **18,** 1812–1815 (1979).
43. H. Kumabe, T. Tanaka, H. Namizaki, M. Ishii, and W. Susaki, "High Temperature Single-Mode CW Operation with a Junction-Up TJS Laser," *Appl. Phys. Lett.* **33,** 38–39 (1978).
44. A. Tebo, "Writing with Diode Lasers," *Electro-Optics,* pp. 56–60 (June 1983).
45. M. Wada, K. Hamada, H. Shimizu, T. Sugino, F. Tajiri, K. Itoh, G. Kano, and I. Teramoto, "A High-Power, Single-Mode Laser with Twin-Ridge-Substrate Structure," *Appl. Phys. Lett.* **42,** 853–854 (1983).
46. D. R. Scifres, R. D. Burnham, and W. Streifer, "Continuous Wave High-Power, High-Temperature Semiconductor Laser Phase-Locked Arrays," *Appl. Phys. Lett.* **41,** 1030–1032 (1982).
47. C. Lindstrom, T. L. Paoli, R. D. Burnham, D. R. Scifres, and W. Streifer, "High Power (2.5W) CW Phase-Locked Diode Laser Arrays with Coated Facets," Paper WB2, presented at the Conference on Lasers and Electro-Optics, May 1982.
48. D. R. Scifres, R. A. Sprague, W. Streifer, and R. D. Burnham, "Focusing of a 7700A High Power Phased Array Semiconductor Laser," *Appl. Phys. Lett.* **41,** 1121–1123 (1982).
49. P. Graf and W. von Tluck, "Sensors in Laser Printers," *Sensors & Actuators* **3,** 41–50 (1982/83).
50. C. Kramer, "Holographic Laser Scanners for Nonimpact Printing," *Laser Focus,* pp. 70–82 (June 1981).
51. M. R. Latta and G. T. Sincerbox, "Holographic Deflector Performance Characteristics Using a Spherical Auxiliary Reflector(A)," *J. Opt. Soc. Amer.* **71,** 1613–1614 (1981).
52. G. T. Sincerbox, "Holographic Scanners: Applications, Performance, and Design," *Laser Scanning Using Mechanical Methods,* G. Marshall, Ed., Marcel Dekker, New York, in press.
53. H. Funato, "Holographic Scanner for Laser Printer," *Proc. SPIE* **390,** Paper 34, January 1983.
54. L. D. Dickson, G. T. Sincerbox, and A. D. Wolfheimer, "Holography in the IBM 3687 Supermarket Scanner," *IBM J. Res. Develop.* **26,** 228–234 (1982).
55. R. Newstead, "The General Optronics 30 Page/Minute Laser Printer," presented at the Institute of Graphics Communications Conference on Intelligent Printers, September 1982.
56. R. N. Blazey and B. E. Cates, "High Quality Laser Printing by Wobble Scanning," *J. Appl. Photogr. Eng.* **6,** 144–146 (1980).
57. J. Montagu, "Laser Scanner for Office Automation," *Electro-Optics,* pp. 51–52 (May 1983).
58. J. Godwin, "A Simple Low-Cost Scanner," *Laser Focus,* pp. 91–93 (October 1981).
59. D. A. Hays, "Electric Field Detachment of Toner," *Photogr. Sci. Eng.* **22,** 232–235 (1973).
60. L. B. Schein, "Microscopic Theory of Magnetic Brush Development," *Photogr. Sci. Eng.* **19,** 255–265 (1975).
61. G. Harpavat, "Electrostatic Field Stripping Model of Magnetic Brush Development," *IEEE–IAS Annual Conference Proceedings,* 1975, pp. 128–134.
62. E. W. Williams, "An Electrostatic Model for Toner Deposition onto a Photoconductor," *IEEE–IAS Annual Conference Proceedings,* 1978, pp. 215–221.
63. J. Nakajima, M. Kimura, and H. Takahashi, "An Analysis of Magnetic Brush Reversal Development," *Fujitsu Sci. Tech. J.* **15,** 115–125 (1979).
64. J. A. Benda and W. J. Wnek, "A Model for Magnetic Brush Development in Xerographic Machines," *IEEE Trans. Indust. Appl.* **IA-17,** 610–618 (1981).
65. K. S. Nelson, "Electrophotographic Development Process," U.S. Patent 4,121,931, 1978.
66. T. Takahashi, N. Hosono, J. Kanbe, and T. Toyono, "Mechanism of Canon Toner Projection System," *Photogr. Sci. Eng.* **26,** 254–261 (1982).
67. W. Imaino and A. C. Tam, "Acoustic Dispersion and Attenuation in Toners," *Advanced Proceedings,* SPSE 36th Annual Conference, 1983, p. 56.
68. W. Imaino, J. Ayala, M. H. Lee, and M. Uyeda, "Measurement of Induced Charge of Monocomponent Toner," *Advanced Proceedings,* SPSE 36th Annual Conference, 1983, p. 52.
69. W. Imaino, K. Loeffler, and R. Balanson, "Charge Transport Experiments in Monocomponent Toners," *Colloids and Surfaces in Reprographic Technology,* M. Hair and M. D. Croucher, Eds., American Chemical Society, Washington, 1982, pp. 249–264.
70. M. H. Lee and W. Imaino, "Time Dependent Charge Transport in Monocomponent Toner," *Advanced Proceedings,* SPSE 36th Annual Conference, 1983, p. 53.
71. J. Alward and W. Imaino, "Magnetic Forces on Monocomponent Toner," presented at the American Physical Society Conference, November 1983.
72. L. S. Chang and A. C. Bettiga, "Toner Distribution Process," U.S. Patent 3,731,146, 1973.
73. L. S. Chang, "Surface for Impression Development in Electrophotography," U.S. Patent 3,754,963, 1973.
74. P. G. Andrus, J. M. Hardenbrook, and O. A. Ullrich, "Microfield Donors for Touchdown Development," *Proceedings,* 2nd International Conference on Electrophotography, 1974, pp. 62–65.
75. L. S. Chang and C. V. Wilbur, "Impression Development," *Proceedings,* 2nd International Conference on Electrophotography, 1974, pp. 74–79.
76. D. A. Hays and W. H. Wayman, "Apparatus, Process for Charging Insulating Toner Particles," European Patent Application 0,071,465, 1983.
77. D. A. Hays and W. H. Wayman, "Apparatus, Process for Charging Toner Particles," European Patent Application 0,071,466, 1983.
78. B. Ehlers, H.-D. Hinz, H. Lobl, and R. Pape, "Electrophoretic Recording of Color Images," *J. Appl. Photogr. Eng.* **9,** 1–6 (1983).
79. As incorporated in Model NP-80, Canon USA, Success, NY 11042.
80. B. Landa, "Process and Apparatus for Transferring Developed Electrostatic Images to a Carrier Sheet, Improved Carrier Sheet for Use in the Process and Method of Making the Same," U.S. Patent 4,364,661, 1982.
81. B. Landa and E. Charlap, "Method and Apparatus for Transferring Developed Electrostatic Images to a Carrier Sheet," U.S. Patent 4,378,422, 1983.
82. G. L. Harpavat, "A Theoretical Study of the Mechanics of a Xerographic Cleaning Blade," *IEEE Trans. Indust. Appl.* **IA-15,** 681–687 (1979).
83. V. M. DePalma, "An Investigation of Residual Toner Removal for the IBM 3800 Printer Subsystem," *Photogr. Sci. Eng.* **26,** 198–204 (1982).

84. L.-H. Lee, "Thermal Fixing of Electrophotographic Images," *Adhesion Sci. Tech.* **9B,** 831–852, (1975).
85. J. C. Azar, A. W. Henry, and R. W. Ferguson, "Externally Heated Fusing Member for Electrostatographic Copiers," U.S. Patent 4,372,246, 1983.
86. A. W. Henry, J. C. Azar, and J. Sagal, "Fusing Member for Electrostatographic Copiers," U.S. Patent 4,373,239, 1983.
87. P. D. Jachimiak, "The Application of Silicone Rubber as a Fuser Roll Material," *IEEE-IAS Annual Conference Record,* 1977, pp. 295–302.
88. J. C. Minor, "Hot Roll Fuser," U.S. Patent 4,357,388, 1982.
89. N. L. Giorgini, "Pressure-Fixing Apparatus and Method," U.S. Patent 4,363,862, 1982.
90. R. D. Archibald, "Laser Printer Fusing System," *Hewlett-Packard J.* **33-6,** 24–26 (1982).
91. G. L. Holland, "Sensing Paper Jams," *Hewlett-Packard J.* **33-7,** 13 (1982).
92. G. Hausmann, German Patent DE2838864C3, 1982.
93. H. S. Kocher, "A Study of Heat Transfer in Toner During Flash Fusing by Means of Electrical Analog Networks," *IEEE-IAS Annual Conference Record,* 1979, pp. 34–42.
94. C. C. Wilson, "A New Fuser Technology for Electrophotographic Printing Machines," *J. Appl. Photogr. Eng.* **5,** 148–156 (1979).
95. J. C. Minor, "A Technical Perspective on the Kodak Ektaprint 250AFB Duplicator," presented at the Seminar on Trends in Office Automation, New York, May 1983.
96. J. Newkirk, "Fuser Member," U.S. Patent 4,375,505, 1983.
97. G. I. Findley, D. P. Leabo, and A. C. Slutman, "Control of the IBM 3800 Printing Subsystem," *IBM J. Res. Develop.* **22,** 2–12 (1978).
98. J. D. Crumly and V. L. Hansen, "Laser Printer Machine Control System," *Hewlett-Packard J.* **33-7,** 11–15 (1982).
99. R. F. Wolter, "The IBM 3800—Electrophotography in Computer Output Printing," *J. Appl. Photogr. Eng.* **4,** 151–154 (1978) and *IEEE-IAS Annual Conference Record,* 1978, pp. 1–5.
100. U. Vahtra and R. F. Wolter, "Electrophotographic Process in a High Speed Printer," *IBM J. Res. Develop.* **22,** 34–39 (1978).
101. C. D. Elzinga, T. M. Hallmark, R. H. Mattern, Jr., and J. M. Woodward, "Laser Electrophotographic Printing Technology," *IBM J. Res. Develop.* **25,** 767–773 (1981).
102. R. A. Juve and D. K. Donald, "Monitoring the Laser Printing Process," *Hewlett-Packard J.* **33-6,** 26–30 (1982).
103. H. Bock, "Toner Concentration Measurements—A Review with a Description of a Flat, Flexible Measuring Coil," *IEEE-IAS Annual Conference Proceedings,* 1978, pp. 222–224.
104. P. M. J. Extra, T. H. J. van den Honert, and J. J. van Lieshout, "Automatic Toner Control," U.S. Patent 4,265,997, 1981.
105. S. J. Bailey, "Proximity Sensor: Key Link in Product Motion Control," *Control Eng.,* pp. 92–96 (October 1981).
106. J. G. Bollinger and N. A. Duffie, "Sensors and Actuators," *IEEE Spectrum* **20,** 70–73 (1983).
107. R. G. Svendsen, "Paper Path of an On-Line Computer-Output Printer," *IBM J. Res. Develop.* **22,** 13–18 (1978).
108. A. Nakai, M. Mori, I. Kondo, and M. Horie," Paper-Loop Control at the Fuser Station of a Laser Printer," *J. Appl. Photogr. Eng.* **8,** 167–171 (1982).
109. K. D. Brooms, "Design of the Fusing System for an Electrophotographic Laser Printer," *IBM J. Res. Develop.* **22,** 26–33 (1978).
110. R. J. Baumbick and J. Alexander, "Fiber Optics Sense Process Variables," *Control Eng.,* p. 75 (March 1980).
111. W. G. Wolber and K. D. Wise, "Sensor Development in the Microcomputer Age," *IEEE Trans. Electron. Devel.* **ED-26,** 1864–1874 (1979).
112. "Present State of Ceramic Sensors," *J. Electron. Eng.,* pp. 73–76 (March 1983).
113. G. A. Lee, "Thin Film Sensors Make an Impact on Moisture Measurement," *Control Instr.,* pp. 33–35 (July 1981).
114. " 'Plain Talk' Duplicator Humanizes Copying," *Design News,* p. 20 (October 1982).
115. K. K. Park, "Talking Copiers and Duplicators," U.S. Patent 4,375,329, 1983.
116. W. S. Jewett, "The Kodak Ektaprint Copier-Duplicator, an Integration of Diverse Technologies," *IEEE-IAS Annual Conference Record,* 1977, pp. 557–568.
117. H. Kondo, "Innovative Technology for Canon Mini-Copier," *Advanced Proceedings,* SPSE 36th Annual Conference, 1983, p. 65.
118. P. Gordon, "Specialized High-Speed Electronics for Document Preparation Flexibility," *Hewlett-Packard J.* **33-6,** 30–35 (1982).
119. B. G. Thompson, "The IBM 66670 Information Distributor," *J. Appl. Photogr. Eng.* **6,** 104–108 (1980).
120. Fujitsu Ltd., M3071A Technical Bulletin, Tokyo, Japan.
121. W. Imaino, R. Kerth, J. C. King, and B. Milander, "Electrophotographic Laser Copier Printer Scanner," *Proc. SPIE* **390,** Paper 14, January 1983.
122. Xerox Corp., 6500 Graphics Printer Technical Bulletin, Rochester, NY.
123. Canon NP Color Copier II, Canon USA, Success, NY 11042.


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**Juan E. Ayala** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Mr. Ayala is an associate engineer with the electrophotographic materials project at the San Jose laboratory. He joined the IBM General Products Division in 1967 in San Jose, where he worked in disk processing and coating, electrophotography, and inks for continuous ink jet until his transfer to the Research Division in 1981. His present interests include toner formulation, development and cleaning physics, and fusing kinetics. Mr. Ayala received his B.A. in chemistry in 1976 from San Jose State University.

**Barbara D. Grant** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Dr. Grant received a Ph.D. in organic chemistry from Stanford University, California, in 1974. She joined the IBM Research Division in San Jose and in 1977 she was appointed manager of the organic synthesis project. In this capacity, she supervised activities in a wide variety of areas including novel organic materials for lithography and packaging, displays, printing, and magnetic and optical storage. She has published and holds patents in the areas of novel radiation-sensitive systems for lithography and holographic applications and new electrochemical systems for printing and displays. In 1981 she became manager of the newly formed I/O Science and Technology Department and is also currently acting manager of the Research electrophotographic materials project. Dr. Grant is a member of the American Chemical Society, the Optical Society of America, and the Society of Photographic Scientists and Engineers.

**Wayne Imaino** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Dr. Imaino is manager of the process sensing project at the San Jose Research laboratory. He joined IBM in 1980. His current interests include charge exchange between surfaces, photogeneration and propagation of acoustic waves in unconsolidated materials, application of spectroscopic techniques to remote sensing and monitoring of manufacturing processes, and the physics of toner development and cleaning. In 1983 he received an IBM Outstanding Technical Achievement Award for his work in lubrication analysis. Dr. Imaino obtained his Ph.D. in physics from Purdue University, Lafayette, Indiana, in 1980. He is a member of the American Physical Society and Sigma Xi.

**Annette Jaffe** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Dr. Jaffe is a Research staff member with the electrophotographic physics project at the San Jose laboratory. She received her Ph.D. in physical organic chemistry from Yale University, New Haven, Connecticut, in 1972. She had a postdoctoral fellowship at the University of Rochester in which she worked on secondary isotope effects and reaction mechanisms, solid state chemistry, and the ESR triplet states in powders and single crystals. Since joining IBM in 1974, her interests have included electrochromic materials, the electrochemistry of stable radical ions, materials for ink jet printing, color science, and print quality. Currently she is involved with new development systems for electrophotography and the materials aspects of toners, carriers, and fusing. Dr. Jaffe is a member of the American Chemical Society and the Society of Photographic Scientists and Engineers.

**Milton R. Latta** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Mr. Latta is a Research staff member in the optical sensing and metrology project at the San Jose laboratory. He received a B.A. in physics from the University of California at Berkeley and an M.S. in optics from the Institute of Optics, Rochester, New York. During the first ten years of his career, he worked as an optical engineer in the IBM General Products Division in San Jose, where he was instrumental in developing the laser optical system for the IBM 3800 non-impact printer. In 1978 he left IBM to work on a laser scanning system for point-of-sale applications. He joined the IBM Research Division in 1980 and worked for two years in the holographic optics group. His current interests include the design of optical systems for utilizing excimer laser radiation for photolithography and material processing applications. Mr. Latta is a member of the Optical Society of America.

**Michael H. Lee** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Dr. Lee is a Research staff member with the electrophotographic physics project at the San Jose laboratory. He has been involved in a number of areas since joining the IBM Research Division in 1975 in San Jose. These include the magnetics of permalloy type materials, the effect of deposition parameters on the corrosion properties of metallic thin films, passivation techniques for metals and semiconductors, and the thermal properties of smectic liquid crystal displays. His current interest is in the physics of development and cleaning in the electrophotographic process. Dr. Lee received his B.S. in engineering physics from the University of California at Berkeley in 1971 and his M.S. in 1972 and his Ph.D. in 1974 in physics from the University of Illinois at Urbana-Champaign. Dr. Lee is a member of the American Physical Society and the Electrochemical Society.

**Sondra L. Rice** *IBM Research Division, 5600 Cottle Road, San Jose, California 95193.* Mrs. Rice is an associate engineer with the electrophotographic materials project at the San Jose laboratory. Her recent interests include various material aspects of electrophotographic development and fusing, excimer laser applications, and magnetic particle dispersions. She received her A.B. degree from the University of Rochester, New York, and her M.S. degree in chemistry from San Jose State University, California. Before joining IBM in 1977, she taught chemistry in private secondary schools in Seattle, Washington, and Endicott, New York. In 1981 Mrs. Rice received a Research Division Award for her work in particulate magnetic recording media, and in 1983 she achieved the First Level Invention Award. Mrs. Rice is a member of the American Chemical Society.