Resistive ribbon thermal transfer printing: A historical review and introduction to a new printing technology

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This paper describes a new high-quality thermal transfer printing process in which a printhead consisting of a linear array of small-diameter electrodes produces highly localized Joule heating of a resistive thermal transfer printing ribbon. The heat generated in the resistive ribbon results in the melting of a thermoplastic ink which is then transferred to a printable medium, such as paper, by contact. The origins of the technology in IBM are discussed, together with a description of the resistive ribbon materials and structure, the printhead, and some experimental printer performance values.

Introduction

The continuing and rapid evolution in the capabilities and cost/performance of office systems has resulted in an increased emphasis upon providing higher function in the output devices. In particular, in the area of printing technologies, there is a major trend toward providing increased function and improved reliability in the printer through the use of microprocessors and newer nonimpact printing technologies. The advent of the low-cost microprocessor technology, of course, allows these devices to be gainfully employed in many ways, from providing improved human factors at the printer interface to monitoring machine performance and, in some cases, being the means by which a technology is raised to a level at which it can be practically used in printing applications. Nonimpact printing technologies are also experiencing considerable growth in their use. This increased interest can be attributed primarily to the improved cost/performance and functional capabilities offered by some of these technologies. In particular, the high-speed, low-noise operation of these printers is also augmented by their capability of providing additional printing functions such as multifont and halftone image printing. Although these latter "image" or all-points-addressable printing functions are characteristic of most matrix printing technologies, the nonimpact printing technologies typically offer higher resolution, higher quality, and higher reliability. Further, the rapidly improving cost/performance available in office systems and microprocessors is providing additional impetus for the development of improved nonimpact printing

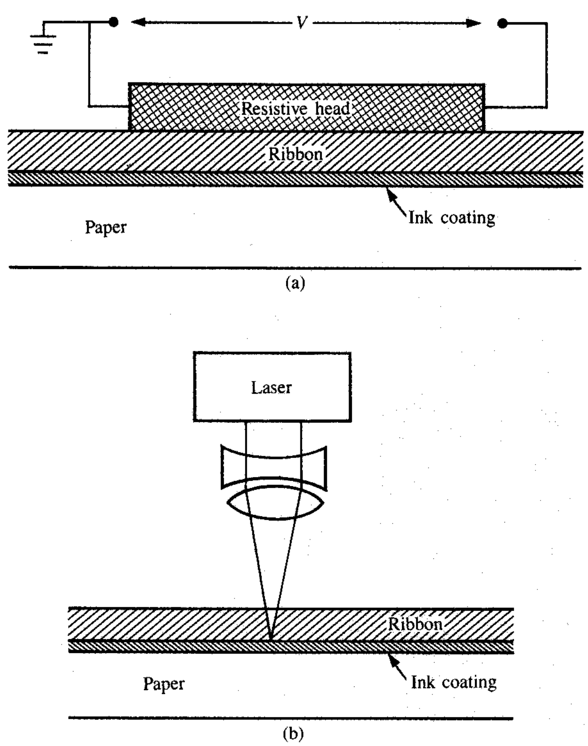

Figure 1

(a) Thermal transfer printing. The electrical Joule heating of a transfer ribbon with small thin film resistors results in local transfer of ink from the ribbon to the paper. (b) Laser transfer printing. Optical absorption of laser beams focused onto the back of the ribbon results in controlled transfer of ink to the paper.

technologies, since these improvements are resulting in a rapid decrease in the costs associated with handling images and composing and printing pages with multiple fonts. Some of the characteristics which are desirable in inexpensive low-end computer output and word processing printers are the following:

1. Print quality equivalent to that of engraved-character printers—at least 240 × 240 pel/inch resolution capability;
2. Low electrical power;
3. Low noise;
4. High reliability;
5. Small and/or low profile;
6. Electronically changeable fonts and pitch;
7. Color;
8. Medium- to high-speed printing capabilities;
9. High-quality printing independent of paper substrate, and specifically on bond paper;
10. All-points-addressable "image" printing capabilities;
11. Acceptable supply costs.

One of the nonimpact printing technologies that has been receiving increased interest in recent years is thermal transfer printing, in which printing is achieved by transferring ink from a ribbon or other supporting structure to paper by local heating of the ribbon. The inked ribbon is held in contact with, or in close proximity to, the paper substrate during the printing process, and various methods of locally heating the inked support or ribbon have been employed [1–4]. The two best-known methods for heating the ribbon structure are

1. Electrical Joule heating of small thin film resistors or silicon devices in contact with the back of the ribbon [**Figure 1(a)**].
2. Optical absorption of laser beams focused onto the back of the ribbon [**Figure 1(b)**].

In the former process, which is employed in many commercially available printers, the local heating results in the melting of a wax-based ink which then transfers to a paper substrate held in intimate contact with the ribbon. In the latter case, which is at present restricted to special applications, the transfer of the ink to the paper has been achieved either by melting of a wax-based ink, as described above, or by sublimation of dyes from the ribbon and their subsequent deposition on a printing substrate. In the latter case, transfer, and hence printing, has been achieved with the ribbon merely in close proximity to the substrate [4].

The thermal transfer printing processes described above have exhibited several disadvantages. For instance, quality printers that employ thin film heaters and similar devices typically operate at relatively low speed due to the excessively long thermal cycle times associated with the heating elements. In order to minimize the problems associated with long thermal cycle times, the thermal transfer inks used are typically wax-based or other relatively low-melting-point inks which are also prone to pressure or contact transfer. These restrictions have resulted in thermal transfer printers that produce a print quality highly dependent upon the type of paper substrate used. The electrical power required, desired printing speeds, size, etc., usually preclude the use of laser transfer technology in low-end, low-cost printers. On the other hand, the ribbon supply costs usually render laser transfer printing technology noncompetitive for high-speed printing applications in all but the most specialized circumstances.

In this paper we describe a new nonimpact thermal transfer printing technology, resistive ribbon printing (RRP) [5–7], which eliminates most of the problems associated with the thin film heater and laser transfer printing processes. The resistive ribbon printing technology satisfies virtually all of the characteristics described earlier as being desirable in a low-end printing technology. For instance, it yields high-quality "engraved" printing on bond and other papers while also having relatively low power requirements (<3.0 J/cm^2).

Also, the RRP technology is a nonimpact, and therefore a noise-free, printing process. The inherent simplicity of the RRP process provides high printer reliability, while its electrically addressable matrix printing characteristics allow both electronically changeable fonts and pitch as well as all-points-addressable "image" printing. Further, color printing has been demonstrated with the aid of special RRP ribbons. Printing speeds in excess of 450 characters per second (cps) have been achieved in special experimental printer configurations (cf. ®QUIETWRITER Printer, 40–50 cps). Theoretically, since there is no observable reciprocity failure, the RRP technology is capable of even higher printing speeds.

Resistive ribbon process

The basic concept underlying the RRP technology required the development and use of both special printing media and special printing heads for selectively transferring ink from the special media to the paper.

In particular, and of special interest, were printing ribbon media that were conductive and which could therefore be subjected to highly localized heating by the passage of an electrical current through the conductive medium. The highly localized heating of the ribbon was achieved by tailoring the electrical contact to, and electrical properties of, the conductive/resistive ribbon. For instance, localized heating of the ribbon was obtained by employing an asymmetrical electrical contacting structure consisting of a printhead with an array of small-area "printing" electrodes and a large-area "return" electrode (see **Figure 2**). The high current densities that arise in the neighborhood of the print electrode during an applied voltage/current pulse produce intense local heating in the neighborhood of the printing electrode. Conversely, since the current densities vary rapidly and are approximately inversely proportional to the cube of the distance from the small printing electrode, the low current densities that occur in regions only slightly removed from the printing electrode do not result in substantial Joule heating of the ribbon in these regions.

In the RRP technology, the intense localized heating of the printing ribbon results in the localized melting of a thermally transferable polymer ink film which is coated on the side of the ribbon opposite to that of the contacting printhead. These melted regions of polymer ink are consequently transferred to a paper substrate which is in contact with the printing ribbon during the electrical printing cycle. This controlled transfer of the polymer ink film from the RRP ribbon to the paper substrate gives this technology a high-quality/high-contrast printing capability.

Also, the use of the RRP technology approach results in several other significant advantages in comparison with most conventional thermal printing technologies. First, the RRP technology has an inherent advantage in printing speed. This speed advantage results from direct generation of heat in a conductive/resistive ribbon which is in contact with the

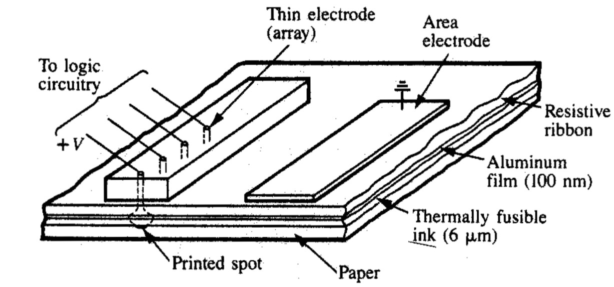

Figure 2

Schematic of an RRP print ribbon and head structure. The asymmetrical printhead or electrical contacting mechanism consists of an array of small-diameter "printing" electrodes together with a broad-area "return" electrode.

paper. Since it is the ribbon and not the printhead that gets appreciably hot, we virtually eliminate any thermal cycle time restrictions that may be associated with the printhead. That is to say, unlike thermal printers that employ thin film heating elements which cannot be moved until their temperature has fallen below the transition temperature for printing, the RRP printhead can be moved as rapidly as desired consistent with the voltage and current parameters employed. The fact that the RRP technology generates heat in the ribbon and not in the printhead also results in further practical advantages. For instance, the elimination of the thermal cycle times associated with the thin film printheads of most thermal printers also allows the practical use of inks which melt at higher temperatures than those allowed with conventional thermal printers. As a result, resistive ribbon printing can use inks that have improved thermal and mechanical characteristics, namely inks that melt at higher temperatures and inks that are not readily transferred by simple contact at low pressures. Conventional thermal transfer printers typically employ wax-based transfer inks which melt at relatively low temperatures in order to minimize thermal cycle times and maximize print speeds. However, the material and mechanical constraints associated with use of wax-based materials usually result in a high dependence of print quality upon the type of paper substrate used. Typically, thermal transfer printers that use thin film printheads to thermally transfer ink from a ribbon to paper also employ special smooth highly calendered papers in the printing process, since the quality of printing degrades severely with the use of papers with rougher surfaces. The resistive ribbon printing technology does not suffer from these constraints.

Other potential advantages of the resistive ribbon printing process are related to the simplicity of the printhead structure. For instance, RRP printers use printheads consisting of an array of contacting small-diameter electrodes. These printhead structures are inherently simpler

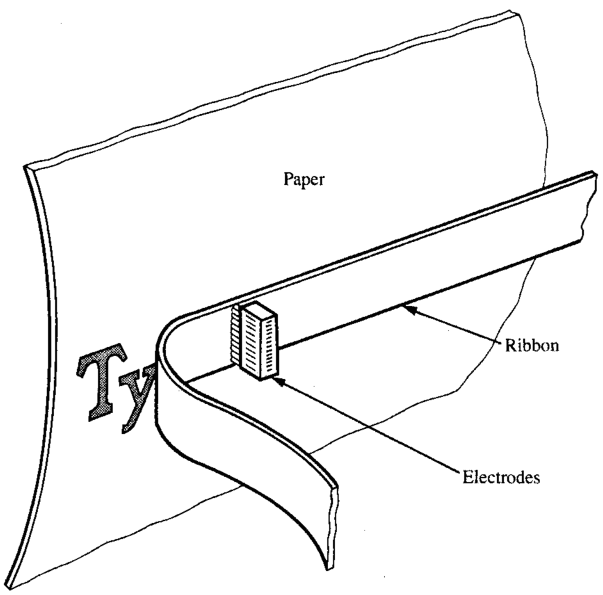

Figure 3

High-quality serial character printer configurations usually employ at least forty 25-μm-diameter electrodes situated on 100-μm centers.

to fabricate and require fewer process steps than are required in the fabrication of thin film and related small-area semiconductor thermal printheads. Because of the material and electrical constraints associated with the fabrication of the small thermal heating elements associated with conventional thermal printers, it is easier to fabricate a high-resolution RRP printhead than it is to produce an equivalently high-resolution printhead for conventional thermal printers.

Ideally the RRP ribbon should be fabricated such that all of the heat is generated in the ink. This approach minimizes the thermal/electrical energy needed for printing and could be achieved by the use of special ribbons incorporating conductive/resistive inks in their structures [5, 6]. Practical considerations, however, led us to concentrate our efforts on simpler RRP ribbon structures in which the heat is generated in a resistive ribbon substrate coated with a thin film of thermally transferable polymer ink (Fig. 2).

Resistive ribbon and printhead structure

During the research and development phase of the RRP technology, several printhead and ribbon configurations were investigated. In this section we describe the characteristics of one of the more practical configurations that emerged prior to its emergence as the QUIETWRITER Printer. Many technical details specific to the QUIETWRITER Printer are described in other papers in this issue of the *IBM Journal of Research and Development.*

As shown in Fig. 2, a carbon-loaded electrically resistive substrate 16 μm thick, with bulk resistivity of approximately 0.8 ohm-cm, is contacted with an array of small, 25-μm-diameter printing electrodes. A 0.1-μm layer of aluminum, which serves as an electrical return path, is deposited on the resistive substrate. The aluminum is in turn coated with a 4-μm layer of thermally transferable polymeric ink. During the printing process the RRP ribbon and head structure is placed in contact with a paper or other printable substrate, with the inked side toward the printable substrate.

When a member of the electrode array is pulsed, current passes from the electrode into the RRP ribbon. This current flows through the resistive carbon-loaded polymer into the thin aluminum film and then flows towards a broad-area return or counter electrode. The high current densities that result immediately under the contacting print electrodes provide intense and localized Joule heating. Sufficient heat can readily be generated to melt the thermoplastic ink and cause it to be transferred to a receiving sheet in contact with the ribbon. In practice, it has been found that the printing conditions required for printing at speeds of 50 characters per second can be obtained by addressing each of the 25-μm printing electrodes with 26-mA, 12-V electrical pulses. Under these printing conditions, the RRP ribbon structure and 25-μm print electrode array described above result in printed spot diameters of approximately 100 μm (240 pel/in.).

High-quality serial character printer configurations usually employ at least 40 25-μm-diameter electrodes situated on 100-μm centers (**Figure 3**). Characters are generated by appropriately pulsing the electrodes in the array as the printhead sweeps across the ribbon. It should be noted that, in general, the best-quality character printing is obtained by switching the electrodes on and off at the beginning and end of character segments rather than by printing individual pels. A photomicrograph of the uppercase character A printed by this means of addressing the electrodes is shown in **Figure 4**. The regions where the electrodes were turned on and off are readily identified in this picture. This method of addressing the printing electrodes results in higher-resolution printing capabilities in the horizontal direction than in the vertical direction; 240 × 480-pel/in. printing is readily achieved with this approach.

Properties of resistive polymer substrate materials

The fabrication of a suitable resistive substrate involved the evaluation of many polymers, conductive pigment particles, solvents, and casting or coating techniques. Relatively early in the printer development and materials evaluation program, it was determined that the resistive ribbon substrate must satisfy the following requirements:

a. It should be electrically resistive to result in adequate Joule heating when the print electrodes are addressed.
b. It should be mechanically self-supporting to avoid handling problems and thermal inefficiencies.
c. It should be physically strong to be able to withstand the physical stresses imposed upon the ribbon during the printing process by the localized thermal heating in combination with the mechanical stresses associated with the ribbon-handling mechanisms.
d. It should be thin (25 μm) to allow sufficient RRP ribbon to be conveniently packaged in a small ribbon cartridge.
e. It should have smooth surfaces to ensure good electrical contact with the ribbon and thereby avoid the arcing or hot spot generation and subsequent ribbon breakage that can occur with rough surfaces. Since smooth ribbon surfaces minimize the development of hot spots as well as printhead-to-ribbon friction, they result in a tendency to produce less "head fouling" due to transfer of ribbon material to the printhead during the printing cycle.

Some of the polymers evaluated during these studies included polysulfone, poly(2,6-diphenyl phenelene oxide)polyvinylidene fluoride, silicone, cellulose acetate polyesters, polyurethanes, polyimides, and polycarbonates. Of these materials, polycarbonates [8, 9] were found to possess the closest match to the desired materials properties outlined above.

Various methods of forming the resistive polycarbonate ribbon were investigated. It was found that extrusion techniques were not suitable for making the RRP ribbons at the desired thicknesses and carbon loadings. Attempts to cast-coat a polycarbonate/conductive pigment dispersion onto a ®Teflon [10] substrate using dichlormethane as the solvent for the dispersion were unsuccessful because the dispersion would not wet the Teflon. Cast-coating onto polyethylene gave improved results; however, ®Mylar [10] was the final material of choice for the coating surface. It was found that the polycarbonate/conductive pigment dispersion could be readily coated onto the Mylar, and after drying (and shrinking) the resulting resistive ribbon substrate could be easily delaminated and removed from the Mylar cast-coating substrate. Although the resistive ribbon surface in contact with the Mylar is smoother than the free "air" surface, this coating process made both surfaces of the ribbon sufficiently smooth to allow subsequent ribbon processing steps to be carried out.

Following considerable testing with conductive particles and pigments, it was determined that electrically conductive carbon black, in particular ®Cabot XC-72 [11], was a suitable conductive pigment. The appropriate pigment loading conditions were determined from consideration of the electrical resistivity as well as the physical strength requirements. It was found that carbon loading of 25–30% by weight resulted in bulk resistivities of the polycarbonate resistive ribbon of 0.96–0.38 ohm-cm. Further, from dynamic and static stress tests it was determined that a thickness of 14–16 μm with 28% loading of carbon resulted in optimum ribbon performance. Typical physical characteristics of the resistive ribbon are shown in **Table 1**.

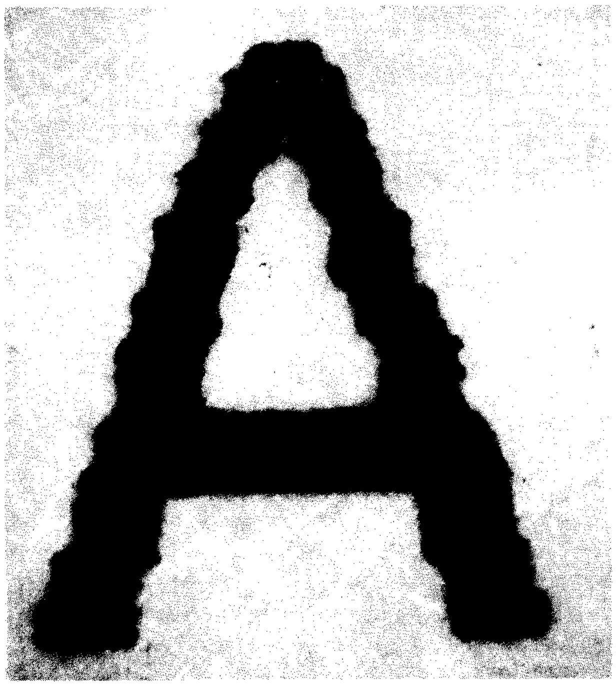

Figure 4

A photomicrograph of the uppercase character "A" printed by the resistive ribbon printer using the matrix electrode head and addressing the electrodes in a pulse width modulation mode. It can be seen that this results in improved horizontal character resolution, with a resulting appearance that is superior to normal matrix or "spot" printing.

Table 1 Typical physical properties of resistive ribbon media.

Tensile strength at break	6500 psi
Elongation	5%
Modulus of elasticity	3×10^4 Pa
Sheet resistivity	400 Ω/□

• *Properties of the conductive interlayer*

The thin conductive interlayer serves two major purposes. First, it acts as an electrical return path of low resistivity. Second, it serves to "focus" the current, since the lowest-resistance path from the print electrode to the return electrode is directly through the ribbon and then via the conductive aluminum interlayer to the return electrode. The presence of the conductive interlayer therefore reduces the current spreading immediately beneath the print electrode. This "focusing" of the current in turn results in improved print resolution due to the improved localization of the

Joule heating that takes place beneath the print electrodes. Several conductive materials were evaluated for use as the return path conductive interlayer. Some of the most thoroughly investigated materials were graphite, copper, gold, and aluminum. These materials were deposited on the resistive polymer by several means including mechanical buffing, electroless deposition, and vacuum evaporation. The best results to date have been achieved with vacuum-evaporated aluminum. The reasons for the improved performance of an evaporated aluminum interlayer are not completely understood at this time. The present results suggest that part of the improved performance is related to the formation of a native aluminum oxide film approximately 4 nm thick at the boundary between the aluminum and the resistive polymer substrate. It is thought that an electrical breakdown in this layer results in a combination of 1) increased heat generation directly at the aluminum/polymer interface and 2) focused current flow in the regions of the oxide where electrical breakdown has taken place [12]. As a result of these effects, it has been observed that printing takes place at slightly lower energies with aluminum than with copper or gold interlayers.

The optimum thickness of the aluminum layer is approximately 100 nm. Thinner aluminum layers tend to lose continuity when subjected to the shear stress present in the ribbon during printing. Further, aluminum layers substantially thinner than 100 nm present considerable resistance in the return path and experience considerable Joule heating during the simultaneous firing of all the print electrodes on a 40-electrode high-quality printhead. The heating that takes place in the aluminum film under these conditions can result in plastic flow of the polymer layer and subsequent breakage of the ribbon. Aluminum film thicknesses greater than 100 nm appear unnecessary at the low print velocities present in a 50-cps printer. With adequate mechanical ribbon strength, an increased aluminum thickness serves only to increase the required print energy while also tending to reduce the print resolution.

Properties of the thermotransferable ink layers

Wax-based inks were used during the initial feasibility tests of the resistive ribbon printing technology. These inks transferred and gave good printing at low print energies. However, these inks also transfer when subjected to mechanical friction or pressure between the ink carrier and the print receptor. In order to overcome these problems associated with wax-based inks, thermoplastic-based inks [13] were substituted.

If the polycarbonate substrate is subjected to too much heat, it softens; this can result in the polymer, together with its conductive carbon particles, being transferred to the print electrodes. The continuing buildup of debris upon the print electrode eventually results in a considerable reduction in print quality. For these very practical reasons it is necessary that the melting temperature of the thermoplastic ink resin be considerably lower than the glass transition temperature of the polycarbonate substrate (150°C).

During the early phases of the RRP ribbon development, W. Crooks and W. Weiche studied several of the materials parameters necessary for the development of a suitable thermoplastic ink, identifying several suitable candidates which produced high-quality printing. Several of these materials were later studied in greater depth and the materials parameters further refined so as to obtain additional improvements in performance. In particular, J. Tsay and D. Shattuck have studied the ink transfer mechanisms, including the dynamics of the transfer process and materials parameters necessary for obtaining high-quality printing. This latter work will be reported in a subsequent publication.

In the early phases of thermoplastic ink development, it was necessary to place considerable emphasis upon the selection of thermoplastic materials. The thermoplastic inks had to meet the basic physical and thermal requirements for print ribbon operation. It was also required that the ink coating process be chemically and physically compatible with the other materials components and processes used in the fabrication of the ribbon. In particular, emphasis was placed upon the selection and refinement of the following materials parameters of the ink: 1) melting temperature, 2) viscosity and flow properties, 3) adhesion to the substrate, 4) flexibility, 5) carbon loading, 6) optimum film thickness, and 7) permissible coating and process solvents. For coating of the thermoplastic ink, a solvent/polymer system was required that could be applied to the aluminum surface of the aluminized polycarbonate ribbon without affecting the integrity of the substrate. The polyimides ®Versamid 940 and 950 [14] were found to provide satisfactory thermal/thermoplastic polymer properties. Loading this polymer with 8% carbon and coating it on the polycarbonate ribbon to a thickness of 4 μm resulted in a ribbon with excellent print quality characteristics. Although several solvents are adequate for use in the ink coating process, isopropyl alcohol gave very satisfactory results and did not tend to soften the polycarbonate substrate during the coating process. Typical electrical driver requirements per print electrode for the resulting RRP ribbons were 26 mA at 12 V printing 10-pitch at 40 cps, which corresponds to a printhead velocity of 4 in./s.

Similar results were obtained by substituting a polyketone resin for the Versamid polyimide in the ink formulation described above.

Printhead materials and structure

Much of the early work in developing the RRP ribbon, with its carbon-loaded polycarbonate substrate, was done using a single wire print electrode. In order to satisfy print speed and quality requirements to meet the objectives of a low-end, high-quality computer output or word processing printer, it was necessary to design and test multielectrode printheads.

Several materials and materials-processing techniques were investigated for use in the fabrication of printheads. After a relatively exhaustive study, tungsten was found to be superior to stainless steel, copper, molybdenum, and other metals. It was also observed that a 25-μm-diameter electrode resulted in the printing of approximately 100-μm spots (240 pel/in.). This resolution was considered the minimum necessary to meet the objectives of letter-quality printing.

During the initial phases of experimentation, excellent-quality printing was achieved with 40-wire printheads that were fabricated by painstakingly stringing tungsten wires in a special fixture and then potting the resulting wire electrode array in RTV resin [15]. These printheads were adequate for further refining and understanding the capabilities of the resistive ribbon printing process. However, it was felt that the fabrication techniques were too costly for use in large-scale manufacturing processes. For this reason, several head fabrication techniques that were more amenable to batch processing and similar manufacturing approaches were investigated. For instance, thin film heads were fabricated by depositing the metallic electrode material onto a ceramic substrate using an appropriate deposition mask. These approaches, however, resulted in poor print quality, primarily due to the fact that the resulting printhead was too rigid to allow all the electrodes in the head to simultaneously follow the contours associated with the paper surface.

After several iterations, the printhead that was finally adopted for the first resistive ribbon printers was fabricated by etching 25-μm tungsten deposited on a polymer substrate. The etched tungsten heads were designed to result in an array of forty 25×25-μm print electrodes on 100-μm centers. As briefly noted above, the printhead must be flexible in order to ensure that all print electrodes remain in contact with the ribbon. The ribbon in turn must flex so as to maintain intimate contact with the paper and thereby ensure reliable ink transfer. The flexibility requirements of the printhead were met by potting the resulting etched tungsten electrode array in silicone rubber and attaching it to a spring cantilever [16]. A polyimide layer was also bonded to the tungsten electrode array during the head fabrication procedures. This polyimide layer served as both a substrate or carrier during the etching of the tungsten electrodes and a means for conducting heat away from the print electrodes during the printing process. This printhead design was used to establish and optimize several printer parameters including printhead-ribbon angle and printhead pressure as functions of print speed. After these parameters were established and optimized for the etched tungsten printhead/print ribbon interface, it was demonstrated that two million characters could be printed at 50 cps with little or no loss in print quality and with acceptable electrode wear. This performance was considered adequate for fulfilling the reliability and sustained print quality criteria necessary for a letter-quality and low-end computer output printer.

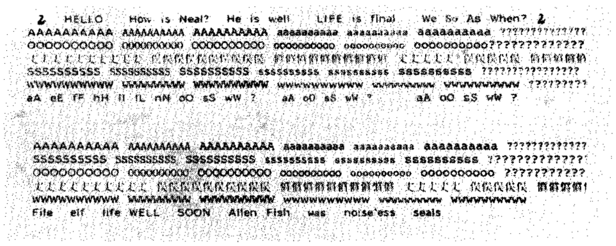

Figure 5

Examples of resistive ribbon printing of various fonts. Electronically changeable fonts are a primary characteristic of the technology.

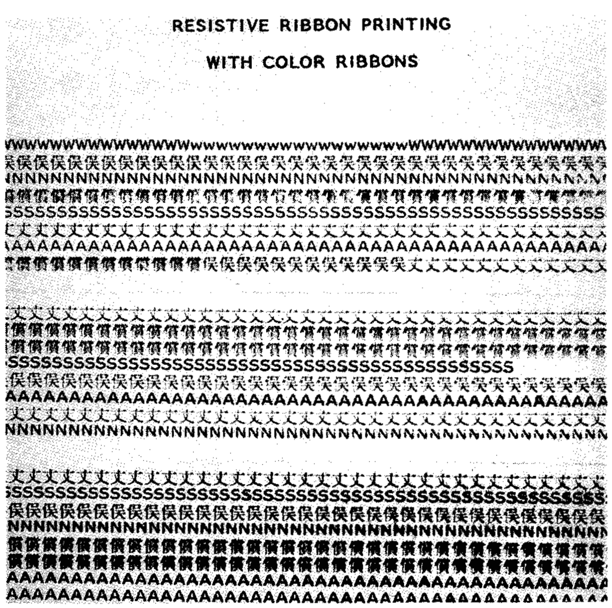

Figure 6

Examples of resistive ribbon printing of various fonts including Kanji using color pigment inks.

Further refinements to the printhead structure specific to the QUIETWRITER Printer requirements were developed later and are described elsewhere in this issue.

Hardware and electronics

The first "printing" done with the RRP technology was done on a static flatbed robot. The robot was equipped with a pulse generator and constant current drivers for the print electrodes. Eventually a drum robot was built to assist in

Figure 7

Examples of "image" or all-points-addressable printing with the resistive ribbon printing technology.

more extensive testing of the RRP technology. In this robot, paper and ribbon were wrapped around a drum and a multielectrode printhead could be swept along the drum as the drum rotated. The complexity of the printhead electronics was increased to a level where it was possible to demonstrate the printing of a variety of characters and several different fonts. During these initial phases, three different fonts as well as Kanji could be printed on the printing robot. **Figures** 5–7 show examples of resistive ribbon printing, including various font styles as well as some later examples of "image" or all-points-addressable printing. For comparison, we include in **Figure 8** photomicrographs of printing done with both the RRP and the ink-jet printing technologies. It is clear that the edge definition obtained with the RRP technology is far superior to that obtained with the ink-jet technology. Further, the print quality obtained with the RRP technology is far less dependent upon the characteristics of the paper or printable media. Unlike ink-jet printing, with resistive ribbon printers the ink does not penetrate the paper. Therefore, "feathering" of characters and dramatic variations in print contrast with the quality of the paper are not significant factors with resistive ribbon printers.

Finally, after several iterations, the ribbon and head structure was mounted on a low-profile printer chassis consistent with a practical product design. An IBM Personal Computer controlled all the printer functions of this robot including font, pitch, print speed, paper feed, etc.

Other applications and observations

During the development of the RRP technology several other applications were investigated. For instance, color ribbons were produced by substituting color pigments and dyes for the carbon in the thermoplastic ink layer. Excellent color printing and color overhead projection foils were generated in this manner (**Figure 9**).

Further, the high quality of the printing combined with the speed, simplicity, and reliability of the RRP process makes it applicable for use in low-end, high-quality facsimile applications. This potential application was demonstrated during the early phases of this work with drum robots.

Finally, another very interesting use for the RRP technology is in the fabrication of short-run offset masters. Since the thermoplastic inks that are transferred during the RRP process can be hydrophobic or oleophilic materials, they can be transferred to the surface of plastic electrostatic offset plates of the type used in photocopiers, resulting in the production of offset masters. It should be noted that because the RRP printer only transfers the ink to the offset master

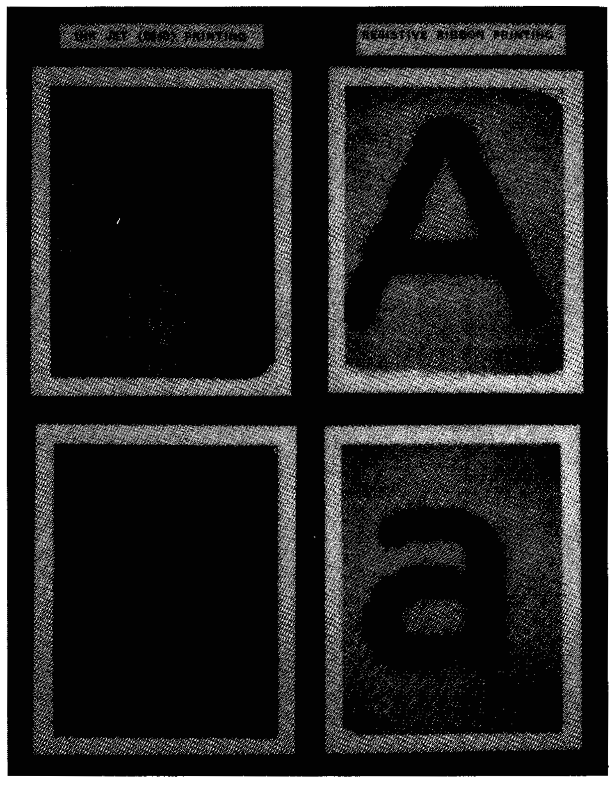

Figure 8

Examples of resistive ribbon and continuous ink-jet printing. Note the "feathering" of the characters with the ink-jet technology. Resistive ribbon printing shows little or no dependence upon the paper substrate quality.

plate in those regions addressed by the printhead, the resulting offset print quality is usually far superior to that produced on the same material by electrostatic copiers. The reason for this, of course, is the absence of any of the background deposition of thermoplastic toners that arises during production of the offset master on an electrostatic copier. It should be noted that we have also produced offset masters of similar quality by using a wide variety of other low-cost 3M offset master substrates.

Conclusions

A nonimpact printing technology, resistive ribbon thermal transfer printing (RRP), has been developed which is applicable to several types of low-end computer output printing applications, such as printers associated with personal computers. In view of the high-quality printing, low noise, electronically changeable fonts, and all-points-addressable (APA) capabilities it offers, the RRP technology should also find rapid acceptance in word processing applications.

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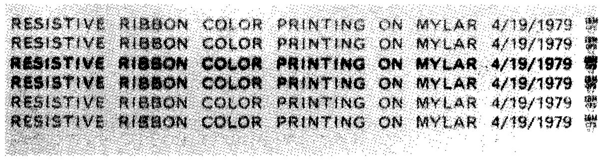

Figure 9

Example of both color printing and overhead projection foil creation by printing on Mylar with the resistive ribbon printer.

References and notes

1. Y. Tokunaga and K. Sugiyama, "Thermal Ink-Transfer Imaging," *IEEE Trans. Electron Devices* **ED-27**, No. 1, 218–222 (1980).
2. M. L. Levine and B. Siryj, "Equipment Applications for Material Transfer Recording," *Proceedings, 11th Symposium on Electron, Ion and Laser Beam Technology*, Boulder, CO, 1971, pp. 69–76.
3. R. S. Braudy, "Laser Writing," U.S. Patent 3,745,586, July 1973.
4. J. T. Jacobs and C. A. Bruce, "Laser Transfer of Volatile Dyes," *J. Appl. Photog. Eng.* **3**, 40–43 (1977).
5. K. S. Pennington and J. L. Mitchell, "Improved Print Head and Ribbon Structures for Thermal Printing Applications," *Research Report RC-5878*, IBM Thomas J. Watson Research Center, Yorktown Heights, NY, 1976.
6. J. L. Mitchell and K. S. Pennington, "Thermal Transfer Printer Employing Special Ribbons Heated with a Current Pulse," *IBM Tech. Disclosure Bull.* **18**, 2695 (1976).
7. L. Montanari and F. Knirsch, "Electro-Thermic Printing Device," U.S. Patent 3,744,611, 1973.
8. W. J. Weiche and M. D. Shattuck, "Improved Physical Strength Ribbons for RRP," Information Products Division, Lexington, KY, private communication (to be published).
9. G. F. Brooks, W. Crooks, and W. J. Weiche, "Polycarbonate Ribbon for Non-Impact Printing," U.S. Patent 4,103,066, 1978.
10. ®Teflon and ®Mylar are registered trademarks of E. I. du Pont de Nemours and Co., Inc., Wilmington, DE.
11. ®Cabot XC-72 is a registered trademark of the Cabot Paint and Pigment Co., Boston, MA.
12. K. K. Shih and D. B. Dove, "Electrical Properties of Resistive Ribbon," *IBM J. Res. Develop.* **29**, 519–526 (1985, this issue).
13. W. J. Weiche, "Rub Resistant Ribbon for Non-Impact Printing," U.S. Patent 4,308,318, 1981.
14. ®Versamid 940 and ®Versamid 950 are registered trademarks of the General Mills Co., Minneapolis, MN.
15. C. H. Hafer and R. L. Street, "Wire Print Head for Resistance Ribbon," *IBM Tech. Disclosure Bull.* **21**, 320 (1978).
16. W. Crooks, C. Hafer, and W. Weiche, "Print Head for High Resolution Electrothermal Printing Apparatus," U.S. Patent 4,456,915, 1984.

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