Laser Toner Fusion: An Imaging Process for Graphic Arts Applications

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Laser-toner-fusion (LTF) is a dry, high quality electrothermographic imaging process for producing both monochrome and color images from electronic input. The process steps involve using a magnetic brush to apply a uniform toner layer to a substrate imagewise exposing the layer to a high power IR laser that tacks the toner to the substrate; removing the unexposed toner using a magnetic brush toner removal device; and finally, fixing the image using conventional fusing. The removed unexposed toner can be recycled thereby eliminating waste. The exposed toner particles are partially buried in a thermoplastic layer and are therefore robust to abrasion. The process is insensitive to visible radiation and can be carried out in ordinary roomlights. The energy required for imaging is between 150 and 300 mJ/cm^2. The application most thoroughly investigated is image setting where color separations with 2540 pixels per inch resolution, and with transmission density of 4.0, have been made to produce high-quality 4-color images.

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Introduction

Laser-toner-fusion (LTF) is a dry, high quality electrothermographic imaging process for producing both monochrome and color images on a variety of substrates, from electronic input.[1] Presently, the major focus of LTF is on image setting, where high quality monochrome color separations are made on a transparent substrate to expose lithographic plates for color printing. However, other applications, such as computer-to-plate (CTP) and proofing have been investigated. LTF marries electrophotography[2] and laser thermal imaging.[3] It utilizes some of the technology found in electrophotography, such as toners, magnetic brush development, and fusing stations, while eliminating others such as corona chargers, photoconductors, and toner transfer stations. The process uses electrostatics to apply a uniform blanket layer of dry powder toner onto a substrate; a high power IR laser to imagewise tack the toner to the substrate; a toner removal device to remove all unexposed toner particles; and finally, thermal fusing to permanently fix the image. One of the many advantages of LTF is the ability to record images on a variety of substrates including film, paper, and lithographic printing plates as examples. The process is insensitive to visible radiation and can be carried out in ordinary roomlights. The images are robust to abrasion because the toner image is partially buried in a thermoplastic layer. Binary halftone color separations have been made at 2540 pixels per inch resolution, and with a maximum UV transmission density of about 4.0; the ultimate resolution is limited by the toner particle size.

Process Overview

The LTF process is schematically shown in Fig. 1 and consists of four basic steps: (a) toner laydown, (b) writing, (c) toner removal, and (d) fusing.

First, a uniform layer of toner is applied to a substrate using a magnetic brush development station similar to those found in conventional electrophotographic copiers and printers. The recording substrate, whether it be film, paper, or lithoplate, must be somewhat conductive or backed by a conductive electrode. This conductivity is required in order to apply a uniform toner layer to the recording substrate, and to electrostatically hold the toner particles in place after they are coated on the substrate.

The second step in the process is writing using a high power infrared laser. Infrared radiation from the laser is absorbed by the carbon in the toner particle causing an instantaneous rise in temperature of several hundred degrees centigrade that softens the toner particles (as well as the substrate) and "tacks" them to the substrate surface and to each other. The partial imagewise melting of the toner layer (and substrate) increases the surface forces thereby creating a differential adhesive force between the exposed and unexposed particles. Exposure can be delivered either incident upon the free surface of the toner (front exposure) or through the support side of the film (rear exposure), if transparent, resulting in different imaging properties. These differences will be discussed in the section on laser writing.

The third step in the process is toner removal. In the LTF process, a very gentle magnetic brush,[4] using "hard" magnetic carrier particles, is used to electrostatically and mechanically remove the less tightly held unexposed

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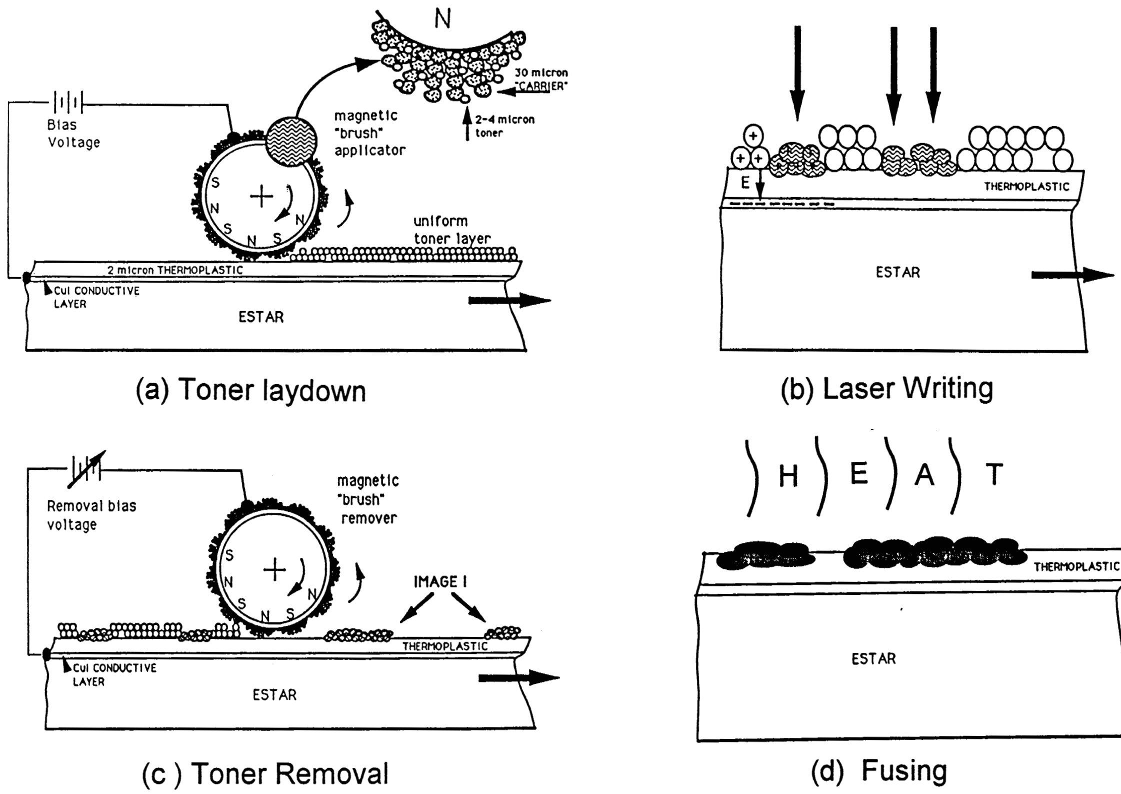


Figure 1. LTF process steps: (a) Toner laydown, (b) Laser writing, (c)Toner removal and (d) Fusing.

particles. The exposed particles remain attached to the substrate. The final step is fusing where the image is permanently fixed to the substrate.

The entire process is insensitive to visible light and hence all imaging steps can be carried out in ordinary lights. Disposable materials used in LTF are plastics and carbon and are therefore easily recycled. There is minimal waste because the unexposed toner particles are removed from the receiver by the toner removal station and recycled.

	Thermoplatic	
1 – 2 microns		Elvacite
	CONDUCTIVE LAYER	CuI
	ESTAR	

Figure 2. Cross section of typical film recording element

Materials

Recording Substrate

One of the many advantages of LTF is the ability to record images on a variety of substrates including film, paper, and lithographic printing plates as examples. A cross section of a typical film recording substrate is shown in Fig. 2. The substrate consists of a 4-mil Estar™ base, a conductive layer of CuI with a sheet resistance ranging between 10^4 to 10^6 ohms per square, and a 2 µm thick thermoplastic layer of Elvacite™. The required magnitude of the conductivity depends, in part, on the process speed for a given application. At higher process speeds, low sheet resistance of the conductive layer leads to nonuniform toner laydown and low toner density due to incomplete development. CuI was chosen as the conductive layer because it can be easily and cheaply solvent coated. It has a sheet resistance adequate for process speeds up to about 5 inches per second and has a low optical density in both the visible (0.03) and UV (0.14) spectrum, a desirable and sometimes necessary property for applications in graphic arts. Elvacite was selected for its surface energy and it is compatible with the toners used in the process and because of its low glass transition temperature (T_g), which allows lower exposures for the migration of toner particles into the thermoplastic layer when heated imagewise. In principle, the thermoplastic layer is not needed and the toner can be applied directly to the conductive layer. However, because of surface energy mismatches and possibly higher adhesive forces, more energy is required to record images on the conductive layer than on the thermoplastic layer. Furthermore, the final fusing step requires less energy with the thermoplastic layer that helps in eliminating distortion of the Estar base, a requirement for imagesetting applications where the four-color separations must be registered to tight tolerances.

Developer

The developer used in the process is dual-component (carrier plus toner) with the carrier consisting of "hard" magnetic particles approximately 30 µm in diameter, and insulating non-magnetic toner particles about 3 to 4 µm in diameter. The toner formulation, needed to meet the imaging requirements discussed previously, is based on the evaporative limited coalescence[5] method. The formulation incorporates a carbon-based pigment along with a binder and charge agent. In order to meet the imaging demands of high transmission density, toner particles with a high percentage of carbon are used. These toners provide higher covering power that allows for a reduction in toner stack height and a subsequent

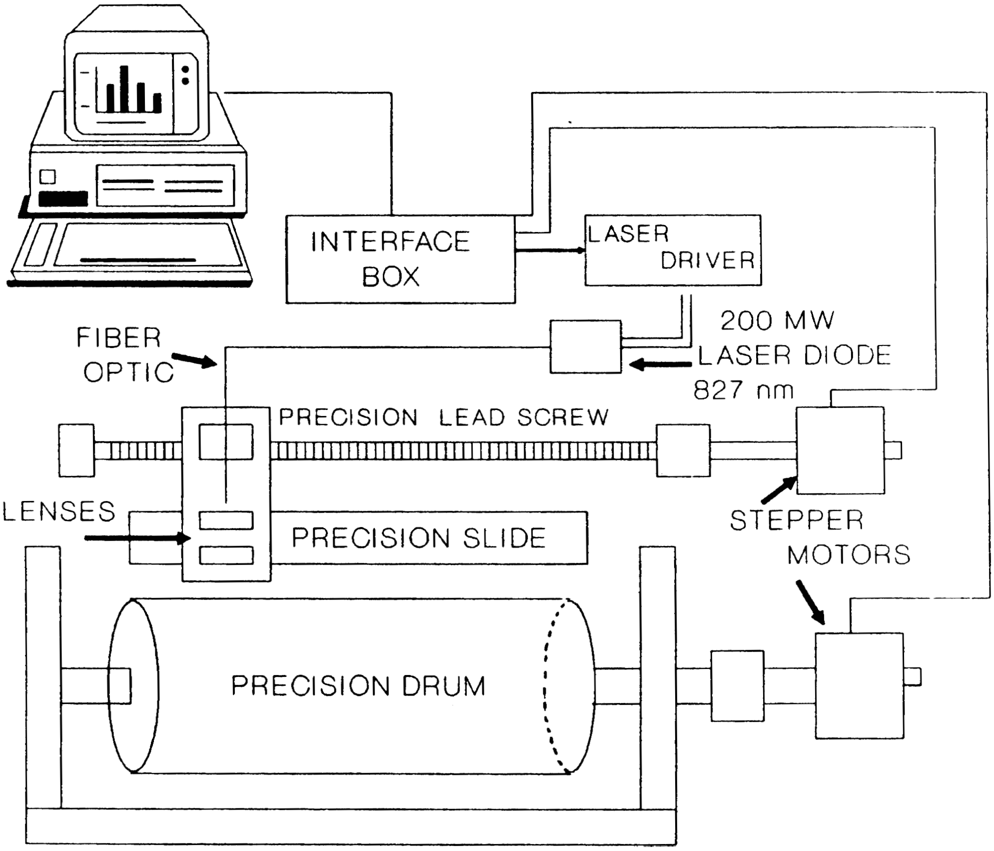


Figure 3. Laser imaging breadboard

reduction in exposure. Pigment concentration of about 12% by weight is used in the LTF process. Higher concentrations were tested but are limited by image artifacts such as pinholes. In addition, at higher carbon concentrations, the unexposed toner is more difficult to remove.

The carrier particles used for toner removal are of the "hard" magnetic type having a coercivity of at least 300 gauss and an induced magnetic moment of at least 20 EMU/gm when in an external magnetic field of 1000 gauss.[6,7] These magnetic properties cause the particles to form chains that flip into magnetic alignment in each new field when exposed to a succession of magnetic fields emanating from the rotating core magnetic. Each flip is accompanied by a rapid movement of the particle chain around the core magnet in a direction opposite to the movement of the rotating core. The observed result is that the carrier particles flow smoothly at a rapid rate thus delivering fresh carrier and toner to the substrate. The coercivity requirement relates to the ability of the carrier to flow on a rotating-core applicator, while the induced-moment requirement relates to the high rate at which the developer flows on such applicators. It is found experimentally that high quality images can be made using LTF with the magnetic carrier and the toner removal device described in the section on toner removal, at much lower exposures than required if more aggressive removal methods are used. This gentle toner removal process results in a significant increase in system speed and in image quality.

Process Configuration

Toner Laydown

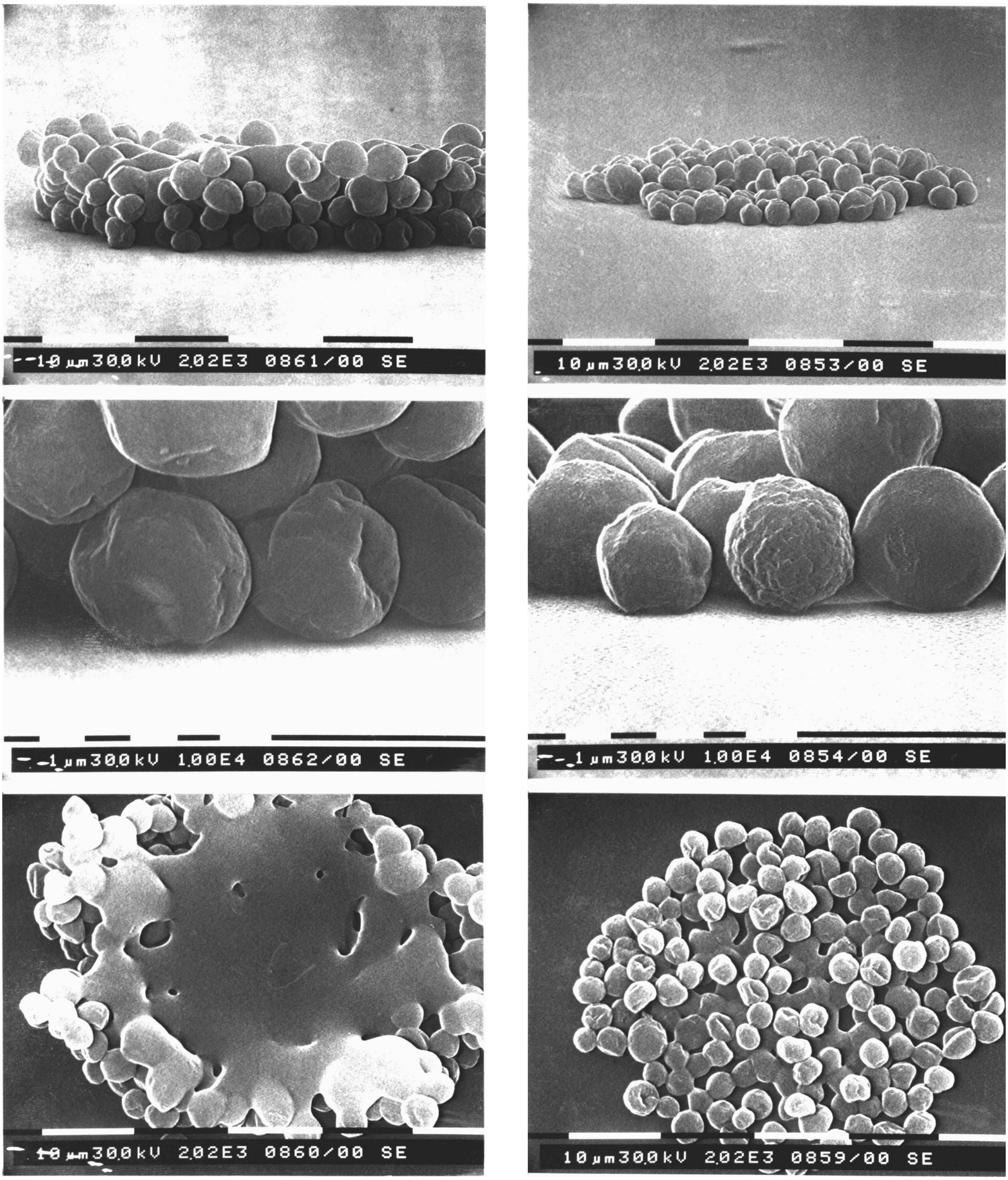
Toner laydown is accomplished by bias developing a uniform layer of toner onto a grounded substrate using a magnetic brush development station. For high image quality and high resolution applications, the toner particle size must be small and the blanket laydown of toner must be uniform, necessitating the use of a development station similar to those currently used in high quality electrophotographic applications. The toner particle is charged and when it is applied to the grounded substrate, it induces an image charge. The coulombic force between the charged toner particle and its image charge holds the toner to the substrate. The toner laydown density and consequently the resulting process density is selected by adjusting the bias voltage applied to the toner laydown station.[8]

The toner laydown station[9] consists of a thin non-magnetic rotating stainless steel shell concentric with a rotating magnetic core. The rotational velocities of the shell and core can be independently controlled. The rotational direction and velocity depends upon the film velocity. Most experiments were done with a film linear velocity of about 1 inch per second and the shell and core rotational velocity set at about 14 and 800 rpm respectively, both rotated in the same direction and cocurrent with the film velocity.

The thickness of the toner layer is selected by adjusting the bias voltage applied to the shell of the toner laydown station. This allows the final image density to be selected to meet the image requirement of any particular application. For example, the UV transmission density for halftone imagesetter applications for prepress markets can often measure above 4.0.

Laser Writing

Images are written using the laser breadboard shown in Fig. 3. The IR laser source is a 200 mw laser diode



(a) (b)

Figure 4. SEMs of (a)Front and (b) Rear exposures.

(Spectra Diode Labs, Inc., Device Type SDL-2420-H2) equipped with an SDL 800 Laser Diode Driver with an output wavelength of 827 nm. The laser beam is coupled by a 100 micrometer diameter fiber optic cable to a 3:1 reduction lens assembly and focused to about a 30 micrometer spot for making images at 1800 pixels per inch resolution. The writing pitch (distance between scan lines) is 25 micrometers and the maximum power focused at the sample plane is about 100 mw. Another breadboard with a smaller laser spot size and smaller pitch is used for making higher resolution images. The laser breadboard further consists of a rotating drum, upon which the biased developed film or paper is mounted, and a translation stage that moves the laser along the drum length. The drum rotation, the laser beam location, and the laser beam power are all computer controlled. An electronically generated continuous tone stepwedge and a binary halftone stepwedge are both used to measure the minimum energy required for imaging. For binary halftone applications, the determining factors in the minimum energy required for imaging are the smallest percentage dot and the maximum density, Dmax, required for the particular application.

Exposure can be delivered to the free surface either of the toner (front exposure) or through the support (rear exposure). LTF toners have a large extinction coefficient in the infrared leading to highly absorbed radiation. Therefore, for front exposure, most of the heat is generated near the free surface of the toner particle and must propagate down the toner stack to the thermoplastic layer to make the toner stick. Rear exposure results in the heat generated near the toner/overcoat interface, causing the thermoplastic overcoat to soften while heat propagates toward the toner free surface. These two exposure conditions result in different imaging characteristics and this is illustrated by the SEMs shown in Figs. 4 (a) and (b) for front and rear exposure respectively.

IR radiation is absorbed near the top surface of the toner for front exposure and the heat must propagate through the toner stack sintering the toner particles and softening the thermoplastic overcoat. The coulombic force between the charged toners and its image charge causes the heated toner to penetrate into the softened overcoat thereby increasing the adhesive force. For applications requiring higher Dmax, the toner stack height increases and the generated heat must diffuse a greater distance. As the heat diffuses through the toner stack towards the thermoplastic overcoat, it is also diffusing laterally, leading to some dot gain. Lateral heat diffusion melts the toner particles in the upper portion of the toner layer, but then less heat is available to soften the thermoplastic overcoat and increase the adhesive forces. When writing high density images using minimum energy, only higher percentage halftone dots (greater than about 25% at Dmax > 3.0) survive the toner removal step. Lower percentage dots are removed by the magnetic brush. The reason for this is because the upper layers of the toner are melted by lateral heat diffusion forming a crust but there are only random spots below the crust where enough heat is available to tack the toner to the thermoplastic overcoat (see Fig. 4). For the smaller percentage dots there are fewer spots where toner has sintered and penetrated into the overcoat to increase the adhesive forces, and the entire dot is only weakly held to the substrate. Although the toner removal process is gentle, the smaller percentage dots are removed. In order to keep these smaller dots either the exposure must be increased which leads to further dot gain, or the toner stack height reduced by increasing the toner covering power (increasing carbon percentage).

When the exposure is delivered from the rear (through the substrate), the radiation is primarily absorbed near the toner/overcoat interface resulting in excellent adhesion to the substrate. However, heat must propagate through the toner stack towards the free surface. If not enough heat is available, the upper layers of the toner stack will not be sintered and are removed in the toner removal step (see Fig. 4). This limits the maximum density attainable with rear exposure, but retains the smallest percentage halftone dots. An interesting feature of rear exposure is that pixel density can be changed by changing the exposure. This gray scale attribute has the potential to further increase image quality.

Toner Removal

During the writing step, exposed toner particles and the thermoplastic layer beneath the particles heat up and soften. The Coulombic force acting on the particles causes them to migrate into the thermoplastic layer resulting in an increase in the adhesive force holding the particles to the substrate. The amount of increase in the adhesive force depends upon the exposure and, under conditions of very high exposures (of the order of 1 joule/cm^2), it is possible to completely fuse the exposed toner particles to the substrate. Under these conditions, any number of rigorous cleaning methods, such as fur brush or conventional magnetic brush, could be used to remove the unexposed toner particles without destroying the image. However, if a more gentle method of toner removal is used,[6] lower exposure (less than 0.3 joules/cm^2) can be employed. At these lower exposures, conventional magnetic brush (or fur brush) cleaners are too abrasive. If toner removal is attempted using a fibrous brush or conventional magnetic brush cleaners that are commonly used in copiers, the image is easily destroyed because these devices are too abrasive.

The magnetic brush configuration used for toner removal is similar to the toner laydown station except that a detone roller and skive are incorporated in the design. A bias voltage of between zero to about – 100 volts is used for toner removal for positively charged toner particles. If unexposed toner removed from the substrate is allowed to remain on the removal roller, the toner concentration begins to rise and reduce the removal efficiency. To maintain high toner removal efficiency, an aluminum detone roller, along with a toner stripping skive, is used to remove toner from the toner removal roller. When a conductive carrier is used for toner removal, the aluminum detone roller is coated with a thin insulating layer to prevent overloading the detone roller bias voltage supply. A novel, dual purpose toner station was designed and built that accomplished both toner laydown and removal in a single station, and also recycled the unexposed toner.[6]

As previously stated, for front exposures using low exposure to minimize dot gain and requiring Dmax greater than about 3.0, all dots smaller than 25% are removed by the toner removal process. In this case, there is a gradual build-up of sintered toner with time, which precludes recycling of the toner. Use of higher exposures and a look-up-table (LUT) to correct for dot gain, can eliminate this problem.

Fusing

Fusing becomes a critical subsystem in the LTF process when used in any application requiring precise registration. For imagesetting applications in graphic arts, high-resolution binary halftone color separations are produced that require registration to within about 25 μm over a 25 cm span. Estar base, the support for the transparent recording element used for LTF, relaxes when heated near its glass transition temperature

(125°C) leading to misregistration of the four color separations. For applications such as color proofing, where the image is on a paper receiver, registration is no longer an issue but there are still other issues such as paper curl and blistering.

Several different fusing approaches were investigated. One approach is convection, where the receiver sheet is placed (image side up) on a glass plate in an oven at 120°C for times ranging from 10 to 60 s. This method provides excellent image quality and abrasion resistance, but unacceptable registration between color separations. Another method is contact fusing using conventional roller fusing. This method provides excellent image quality and abrasion resistance, and also results in good registration if the pressure roller (behind the Estar base) is maintained at, or near, room temperature, while the fusing roller is kept at temperatures below 150°C. It is believed that the Elvacite layer acts as an insulator between the Estar support and the heated fuser roller. The exact temperature of the pressure and fuser rollers depends, of course, upon the rate of fusing. If process speeds greater than about 2 in. s^{-1} are employed, higher temperatures can be used.

As stated previously, under high exposure conditions, it is possible to completely fuse the exposed toner particles. The exact exposure required to fuse the toner depends upon a number of factors including absorption properties of the toner, pixel density, resolution (smallest percent pixel), and whether the exposure is delivered from the front or from the rear. When fusing is accomplished by high exposures, there is no significant misregistration between color separations because very little heat reaches the Estar support.

Of the three fusing methods described above the preferred one is roller fusing. This method results in excellent registration and image quality, maximizes throughput, because lower exposures are needed to thermally tack the toner to the substrate, and higher fusing speed can be used.

Graphic Arts Applications

Imagesetting

The most intensively investigated application of LTF is for digital imagesetting for graphic arts pre-press markets. In this process, halftone color separations are made for direct UV contact exposure of lithographic printing plates, as an optical mask for color proofing, or for contacting or duping to silver film. Ultimately, multiple lithographic plates are exposed, processed, mounted, and registered in a press and used with their corresponding inks to rapidly create high-quality halftone color images on paper.

The LTF process was integrated with a modified Kodak Approval™ digital color proofing system. This system has an average laser spot size of about 30 µm ($1/e^2$), is capable of 1800 pixel per inch resolution, and has a total of 10 lasers, 8 writing lasers and 2 “edge” or “fill” lasers. Four-color 150 lpi halftone separations were made from 8″ × 10″ digital graphic arts test images (Seybold targets “musicians”). For all four separations, the Dmax ranged between 3.5 and 3.8 and the Dmin were between 0.13 and 0.15 , all measured in the UV. All halftone dots in the range 5% to 95% were retained. A look-up-table (LUT) was used to correct for dot gain due to the high exposures required to hold the smaller dots and prevent blocking at the higher dot coverage while maintaining a high Dmax. These separations were then “proofed” using the Kodak Signature™ color proofing system, yielding high quality full color “press-like” images on paper.

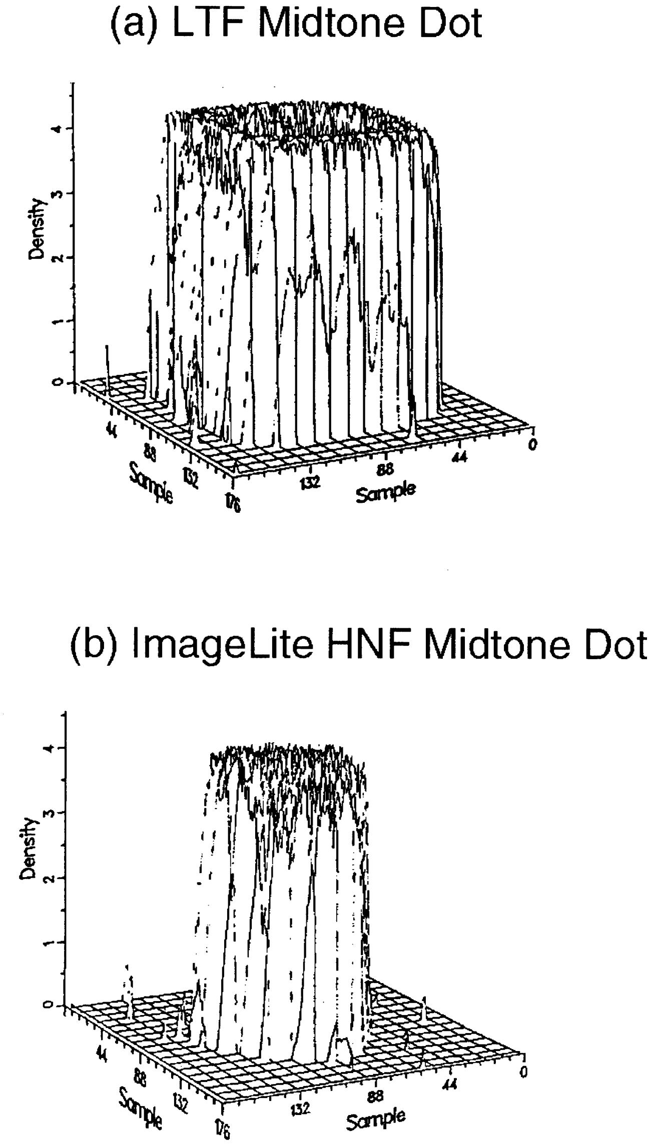


Figure 5. Measurement of edge sharpness of halftone dots.

LTF provides some practical advantages when compared to traditional silver-based imagesetting systems. The process is dry and does not require or produce any silver-containing liquids, or other materials that would require mandatory environmental management. Because of its relative simplicity, the entire LTF process can be implemented in a much more compact allotment of equipment space. In addition, unlike silver-based systems, the process is insensitive to any ambient room light. Finally, measurements have shown that the high contrast edge sharpness of dots and lines is comparable to the best silver systems. This is illustrated in Fig. 5 by a comparison of edge sharpness for halftone dots made with LTF and dots made with a silver-based film. Figure 5 (a) and (b) shows a 3-D plot in density space of midline dots made using the LTF process and Kodak ImageLite™ HNF scanner film, respectively. The maximum density in both cases is about 4.0 and edge density profiles are similar.

As stated earlier, the sensitivity of the LTF process depends on several factors, including the choice of exposure direction (front or rear), the solid area density requirements, and even the minimum halftone dot requirement, which in turn determines the laser spot size and pitch. With this in mind, the sensitivity of the process is roughly 250-350 mJ/cm^2 to produce 2-98% halftone dots at 150 lpi with a maximum density of 4.0, using front exposure.

Computer-To-Plate

Preliminary work has been done to investigate computer-to-plate (CTP) applications of LTF. In this application, toner is applied directly to a lithographic plate and it becomes the oleophilic, or ink receiving, material on the plate. The use of polymeric toner-based processes for the creation of oleophilic areas on lithographic plates is historically well established. Such toner-based plates are known and are presently in common use, but are generally considered to have lower quality (resolution and run length). This inferior quality is often due to variability of full process electrophotography used to produce them. The complexities of these processes impose fundamental constraints on the choice of toner polymers, plate materials, and on the achievable image quality characteristics. Use of the simpler LTF process removes most of these constraints and can lead to long run, higher quality, and toner-based plates on a variety of substrates. Higher resolution and dot edge quality is achievable with LTF because it is a direct imaging process that does not require a toner transfer step.

LTF has been used to apply oleophilic toners on a variety of substrates including polyester films, aluminum plate materials, polymeric and metallic drums, waterless plate surfaces, and papers. Several small plate samples were made from experimental toners and tested on an in-house accelerated wear-testing device, that simulated lithographic press-like conditions. These experiments, and other tests on an actual press of toner plates made via full process electrophotography, indicate that toner plates can easily be made, and they are suitable for press runs of 100–400 K impressions. The relative simplicity of the LTF process (compared to electrophotography) allows a wider choice of durable and oleophilic toner polymers to improve plate performance.

The unexposed toner removal process becomes especially critical in CTP applications, because any unimaged toner left behind on the printing plate contributes to unacceptable background, i.e., “scumming” in the printed image. If necessary, increased laser exposure can be used for platemaking, thus eliminating the final fusing step, and making more efficient or rigorous background cleaning technologies feasible. With increased laser exposures, another practical method also becomes feasible, i.e., to allow the few remaining background particles to be removed by the lithographic inking system during initial press “roll-up”. Although the cleaning step is critical, any of these approaches could be viable.

Contrary to the requirements of imagesetting, high optical density is not required for platemaking. Therefore, resolution and sensitivity capability could even exceed the figures mentioned above. Because the toner layer required for platemaking is much thinner, less energy is required to initiate acceptable toner adhesion. In addition, lateral heat diffusion during laser exposure, which can lead to dot gain, will be less. Because development work for this application was limited, firm sensitivity values were not established. However, a 2X improvement in sensitivity over measured exposures for imagesetting seems reasonable, because the toner stack height is easily reduced in half. This would yield a process sensitivity of between 125–175 mJ/cm^2. Halftone imaging of 1–99% dots at 150 lpi would also be reasonable with the thinner toner layers. LTF platemaking only requires establishing a surface that is oleophilic and durable.

Proofing

Although the main development effort for LTF was for making high-quality color separations for lithographic printing, LTF can also be used to make reflective color as well as black and white images. The same procedure as outlined above is used except that, after the toner removal step for the first color toner, the process is repeated for the remaining colors. That is, the second color toner is bias developed on top of the first toner after the exposure and toner removal steps have been completed. After all three (or four) color toners have been imaged, the image is given a single final fusing step. In addition, a different bias development voltage may be required for each of the toners depending on the charge-to-mass ratio of the particular toner. One of the difficulties in making color images using LTF is that magenta and yellow toners do not normally absorb infrared radiation. Therefore, infrared absorbing dyes or pigments must be incorporated into either the toner formulation or the thermoplastic substrate to impart IR sensitivity. However, almost all of the appropriate IR sensitizers have unwanted absorption in the visible spectrum. If the IR sensitizer is placed in the toner, particle color balance will suffer and if placed in the thermoplastic layer, visible or UV D-min of the recording element will be increased. A way out of this dilemma is to include a bleachable composition of an acid photogenerator along with the IR sensitizer.[10] The use of the bleachable composition eliminates any unwanted absorption of visible radiation from the resulting imaged element. An additional process step of blanket UV radiation is required to effect bleaching.

A limited amount of work has also been done on paper substrates. The paper has to be somewhat conductive as stated above, and grounding is accomplished by using vacuum grooves to hold the paper against a grounded metal surface. A variety of papers were tested, and of these, coated dielectric papers gave the best results as far as uniformity of toner laydown and overall image quality. “Plain” papers had a tendency to trap toner particles in the micro-fiber structure of the surface making it difficult to remove all unexposed particles.

Both color images (color proofing) and black and white images can be made via LTF. High-quality black and white reflective copy was once used extensively for paste up pre-press work with graphic arts cameras. Modern workflow has replaced most of this with digital imagesetting. However, black and white copy is still used in pre-press work for proofing preliminary digital files, for confirming proper content and placement, and for checking final imposition (e.g., “bluelines”).

Summary and Conclusions

This article describes a new dry-writing process called laser-toner-fusion (LTF). The process is simple, robust, and is applicable to a number of graphic arts applications such as imagesetting, color proofing, and computer-to-plate printing. The process is capable of high quality

(2540 pixels per inch) imaging. The laser power requirements are between 100 mJ/cm^2 to 300 mJ/cm^2 depending on the application and required maximum density. These power requirements can be reduced through further development of the toners formulation and recording substrate.

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