

Laser Toner Fusion: An Imaging Process for Graphic Arts Applications

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Abstract

Laser-toner-fusion (LTF) is a dry, high-quality electrothermographic imaging process for producing 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, which 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 imagesetting 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.

Introduction

Laser-toner-fusion (LTF) is a dry, high-quality electro-thermographic imaging process for producing images, on a variety of substrates, from electronic input.[1] Presently, the major focus of LTF is on imagesetting, 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. This process 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.

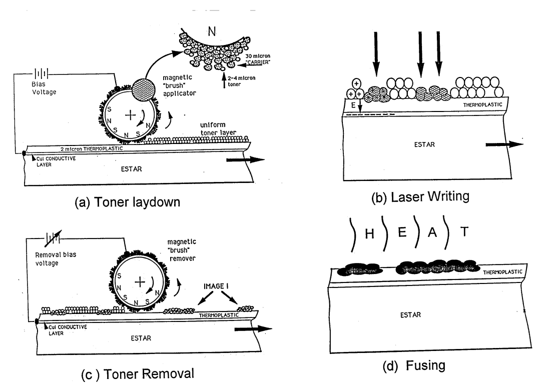

Figure 1. LTF process

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 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, which 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,[2] using "hard" magnetic carrier particles, is used to electrostatically and mechanically remove the less tightly held unexposed particles. The exposed particles remain attached to the substrate. The final step is fusing where the image is permanently fixed to the substrate.

Materials

Recording Substrate

A cross section of a typical film recording substrate used for imagesetting is shown in Fig. 2.

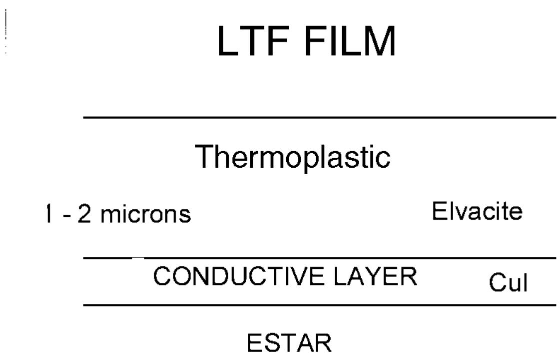

Figure 2. Cross section of recording substrate

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-micron thick thermoplastic layer of Elvacite. CuI was chosen as the conductive layer because it can be easily and cheaply solvent coated, 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, which is compatible with the toners used in the process and because of its low glass transition temperature (Tg), which allows lower exposures for the migration of toner particles into the thermoplastic layer when heated imagewise.

Developer

The developer used in the process is dual-component (carrier plus toner) with the carrier consisting of "hard" magnetic particles approximately 30 microns in diameter, and insulating non-magnetic toner particles about 3 to 4 microns in diameter.[3,4] The toner 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, which allows for a reduction in toner stack height and a subsequent 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. Also, at higher carbon concentrations, the unexposed toner is more difficult to remove.

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. The toner laydown station[5] 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 co-current 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 for 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 pre-press 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 (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, which moves the laser along the drum length. The drum rotation, the laser beam location, and the laser beam power are all computer controlled.

Exposure can be delivered to either the free surface 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 and 5 for front and rear exposure respectively.

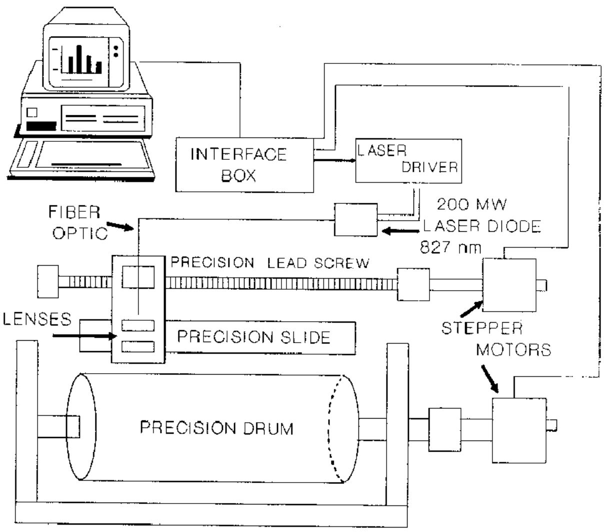

Figure 3. Laser writing breadboard

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. 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 D-max > 3.0) survive the toner removal step, while 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. Even though 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.

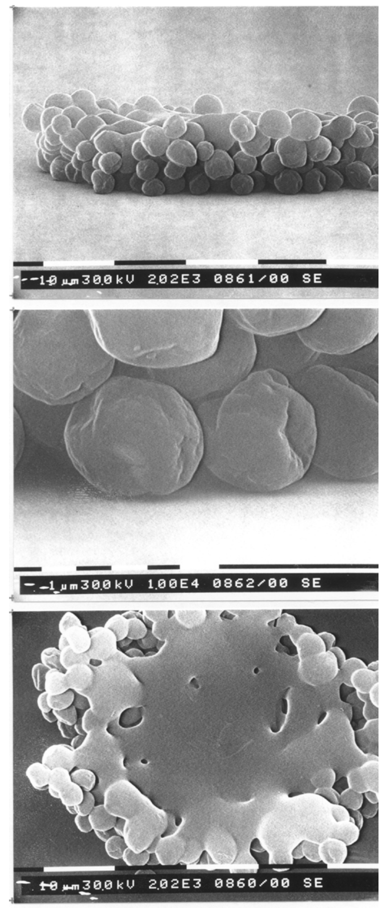

Figure 4. SEM of front exposure

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/cm2), 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,3 lower exposure (less than 0.3 joules/cm2) can be employed. At these lower exposures, conventional magnetic brush (or fur brush) cleaners are too abrasive and if toner removal is attempted using a fibrous brush or conventional magnetic brush cleaners commonly used in copiers, the image is easily destroyed because these devices are too abrasive.

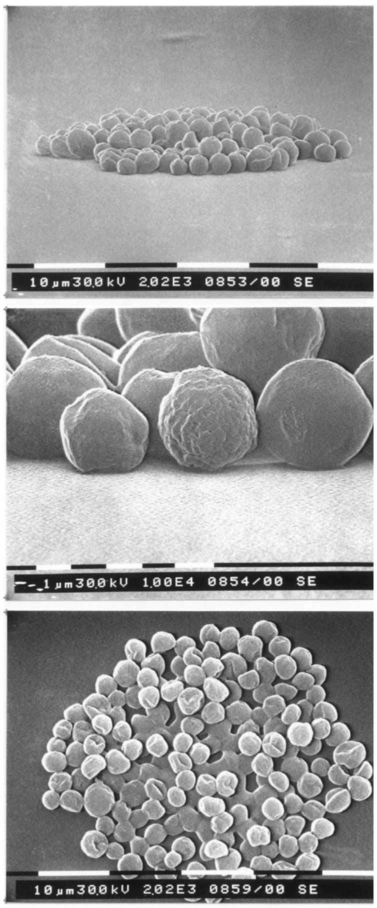

Figure 5. SEM of rear exposure

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 a negative 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 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]

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 microns 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.

Several different fusing approaches were investigated: convection, contact roller fusing, and laser fusing. 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.

Imagesetting

The most 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, or 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.

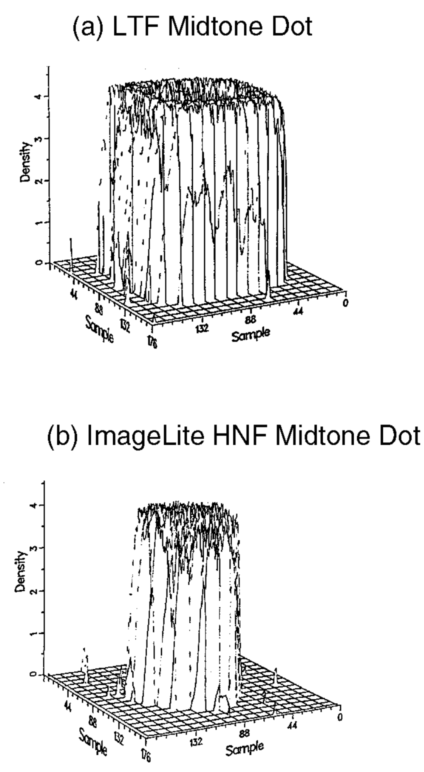

Figure 6. Measurement of edge sharpness of halftone dots

The LTF process was integrated with a modified Kodak Approval™ digital color proofing system capable of 2540 ppi resolution. Four-color 150 lpi halftone separations were made from 8” x 10” digital graphic arts test images (Seybold targets: “musicians”). These separations were then “proofed” using Kodak Signature color proofing system, yielding high quality full color “press-like” images on paper.

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. Also, 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 6 (a) and (b) shows a 3-D plot in density space of midtone 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.

Summary and Conclusions

This paper 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 development of the of the toner formulation and recording substrate.

References

1. C. DeBoer, D. R. Kamp, and Mey, W., U. S. Patent #5,227,265.
2. Kamp, D. R. and Mey, W., U. S. Patent #5,138,388.
3. Miskinis, E. T. and Jadwin, T. A., U. S. Patent #4,546,060.
4. Miskinis, E. T., Designing Materials For The Coloredge Copier Program, SPSE, Sixth International Congress on advances in Non-Impact Printing Technologies, Orlando, FL (1990).
5. To avoid confusion, a magnetic brush development station is referred to as a toner laydown station because, in this case of LTF, it is used to apply a uniform toner layer and not to develop a latent image.
6. Yousey, K. et al., U. S. Patent #5,229,825.

Biography

William Mey is a Research Fellow at Torrey Pines Research currently working on printing technologies. Prior to joining Torrey Pines Research, he was a Research Associate at Eastman Kodak Company working in the area of non-impact printing technologies that included electrophotography, electrography, laser thermal, and inkjet. He has about 40 patents issued and has authored a number of scientific publications. He received his Ph.D. in Physics from Tulane University in 1973.

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