Laser Thermal Media: The New Graphic Arts Paradigm

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For nearly all of this century the graphic arts industry has been using silver halide based images in all stages of production up to the final burning of the lithographic plate. Now the industry appears on the verge of a tectonic paradigm shift to media that dwell under the names "direct to plate," "computer to plate," "direct to press," and "computer to press." Although the new media come in many species, most all of them have two things in common: they don't use silver halide and they do employ a laser thermal procedure. The term "laser thermal" implies that the basic mechanism of the process is thermal and that the heat is derived from a laser beam. As the market develops, we find that diode lasers are the overwhelming choice for heat sources and, in fact, may be the key enabler of the new products.

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Introduction

The field of photothermal and photoacoustic phenomena is an active one. There is a Gordon Research Conference devoted to the topic. However, for the most part the field is centered on relatively high-power effects, where the physics of the materials is nearly that of a plasma, that is, where actual ionization of the molecules occurs. The regime occupied by graphic arts materials and processes is of considerably lower power, near the borderline between sublimation and ablation. The definition of ablation, in this case, is as follows: if a process involves sublimation, that is, evolution of a gas of molecules, and addition of an increment of energy changes the process so particles or aggregates of molecules are now evolved, the evolution of particles is called "ablation" while the evolution of individual molecules of gas is called "sublimation." Both processes can be present in a given event. In some discussions it is useful to distinguish between the two processes, but for most events involving the transfer or movement of materials it is simpler to lump them together and call it laser thermal ablation.

Let me also clear up another point of nomenclature. Thermal printing with a fax-head-type printer (resistive heaters) is often called "sublimation printing" to distinguish it from wax transfer printing. The difference is that wax transfer printing is binary, i.e., full density or no density at each pixel, while the so called "sublimation printing" is continuous tone with many possible levels at each pixel. The problem is, the actual mechanism of fax-head printing is diffusion, not sublimation. It was termed "sublimation" printing because it used sublimable dyes from the polyester fabric printing industry. Laser thermal printing, because it involves an air gap, is actually sublimation printing with a variable amount of ablation printing also operative.

The earliest report of a thermal imaging process related to graphic arts is by RCA workers in 1971.[1] A typewriter ribbon was used as a color donor, with paper as the receiver. Focusing a laser beam through the base of the ribbon gave a transfer of ink to the paper. Estimates of the energy required were about one joule per square centimeter. The fundamentals of the process have not changed very much in the ensuing 26 years. W. C. Myers[2] reported in 1971 writing spots of metal coalescence one-third to two-thirds smaller than the nominal diameter of the laser beam, and attributed the effect to the thermal threshold needed for a laser thermal process. In 1977 IBM workers Bruce and Jacobs[3] reported laser thermal dye transfer images from off-the-shelf dyes such as crystal violet and methyl green coated in a nitrocellulose binder. They showed the direction of the future by using a computer to control the position and modulation of the laser beam and also noted the sharp edges of the printing, again attributed to the thermal threshold of the process.

The first commercial product using a laser thermal process was called Laser Mask. It was described at an SPIE[4] meeting in 1980. The product consists of a coating of fine graphite particles dispersed in an oxidizing binder such as nitrocellulose on a polymer base such as polystyrene. It is exposed through the base with a YAG laser system to ablate the carbon that is transferred to a paper receiver in contact. The result is a negative film and a positive proof on the paper. The negative can then be used to burn a lithographic printing plate. The method gives good results,

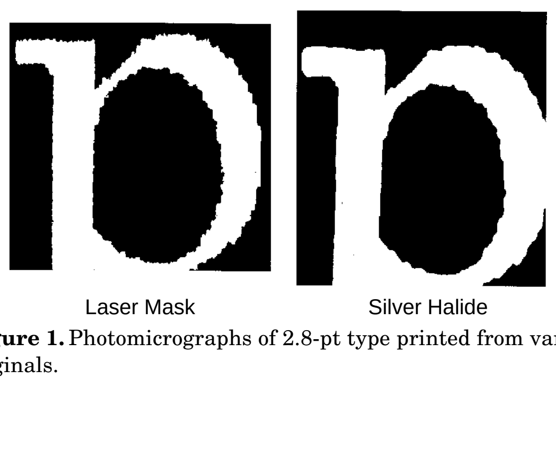

Figure 1. Photomicrographs of 2.8-pt type printed from various originals.

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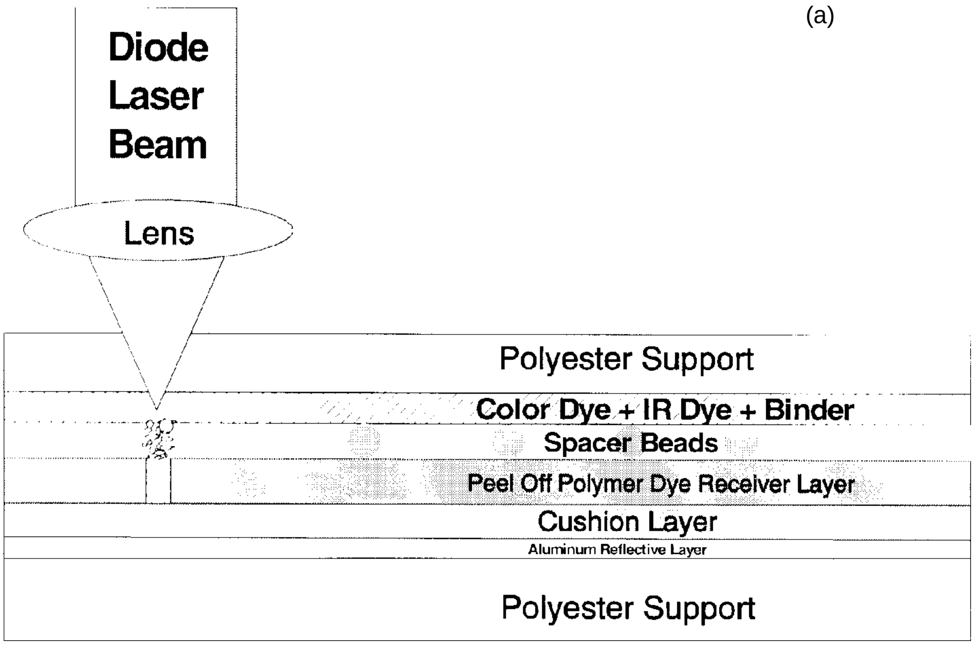


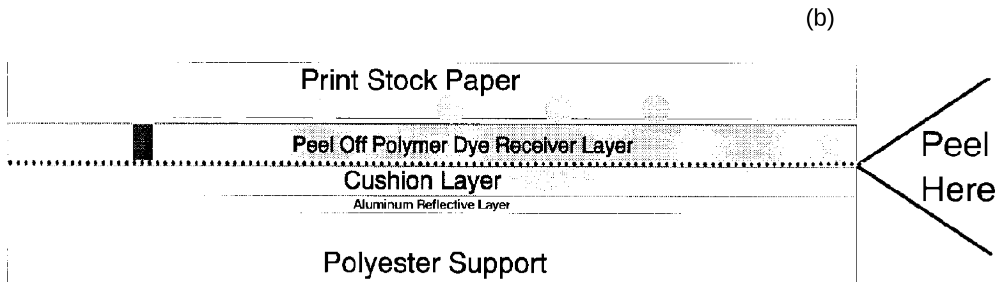


Figure 2. Kodak Approval direct color proofing system: (a) imaging, (b) lamination transfer of the image to print stock paper.

better than silver halide, when used with a high-resolution laser. Figure 1 shows a photomicrograph of 2.8-pt type printed on a Laser Mask original with an 8 μm ($1/e^2$) 830-nm diode laser and a silver halide contact dupe of the same original. While the Laser Mask edges are slightly ragged, there is much less rounding of the pixel edges than the silver halide shows. The Laser Mask original gives a more accurate rendition of the digital data. The Laser Mask product does have some shortcomings. The film is far more scratch sensitive than silver halide films. Its density is somewhat lower than silver halide. However, the big drawback of the system is that the YAG laser requires substantial maintenance and down time.

In the same year as the report of Laser Mask (1980) a UK patent application (GB 2,083,726) was filed by T. W. Baldock from 3M. This described a method of making direct laser thermal printed images on a rotating drum printer with a YAG laser. Both continuous tone and halftone images were described. The dye donor films consisted of a volatile dye coated with a carbon dispersion in ethyl cellulose. Cyan, magenta, and yellow coatings were described along with a black coating consisting: of a mixture of the three color dyes. A double drum machine of the kind used in the graphic arts industry was utilized with the original image scan on the first drum used to modulate the writing laser on the second drum. After printing each color record, the only process reported was hot metal roller fusing of the image into the polymer-coated paper receiver surface. The system was never commercialized. At that time YAG lasers required considerable maintenance, a large and sometimes hidden factor in commercial decisions.

In the late 1980s high-power (100 mW) diode lasers first became available from Spectra Diode Labs, San Jose, CA. When these lasers were installed in laser thermal writing systems, maintenance free laser thermal writing finally became possible. These lasers proved reliable, low noise, and capable of direct modulation by current drivers. Very simple writing systems were then available for the development of laser thermal media.

Color Proofing

The first product that Eastman Kodak commercialized was the Kodak Approval direct color proofing system. A schematic diagram of the system is shown in Fig 2. In the Approval system, the diode laser beam is focused onto a dye layer where it is absorbed by an infrared dye that converts the radiant energy into heat. The heat causes the color dye to transfer to the polymer layer of the intermediate receiver. After each color is written, the dye donor film is removed and replaced with the dye donor him of the next color. When all the colors have been printed, the intermediate receiver is laminated to the printing stock to give the final proof.

At the beginning of the development of the Approval product, the principal virtue of the system was considered to be the dry, no process feature. In practice, the reliability and repeatability of the system have also proved very important. The origin of this feature is the absence of chemical or electrostatic amplification. Amplification works on both the signal and the noise of a system. Sometimes the importance of noise amplification is overlooked.

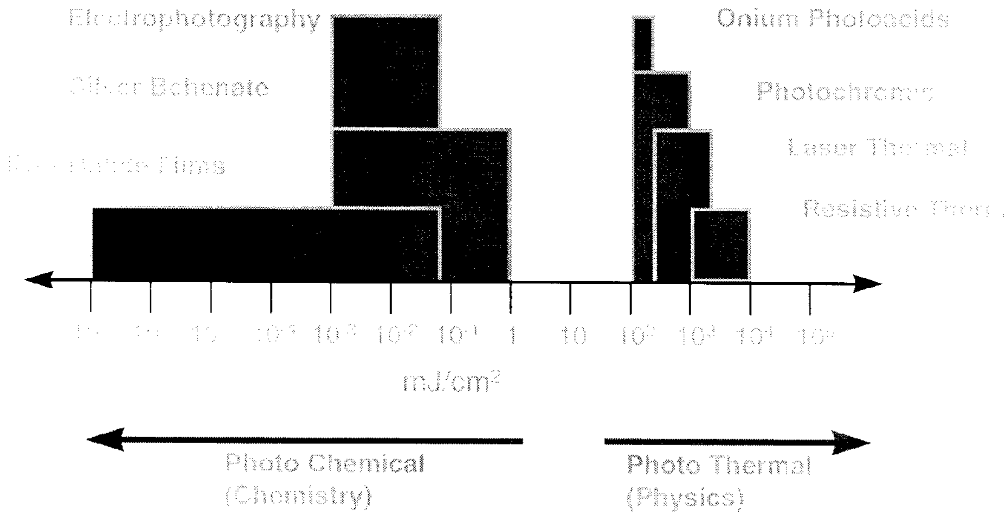


Figure 3. Relative media sensitivity.

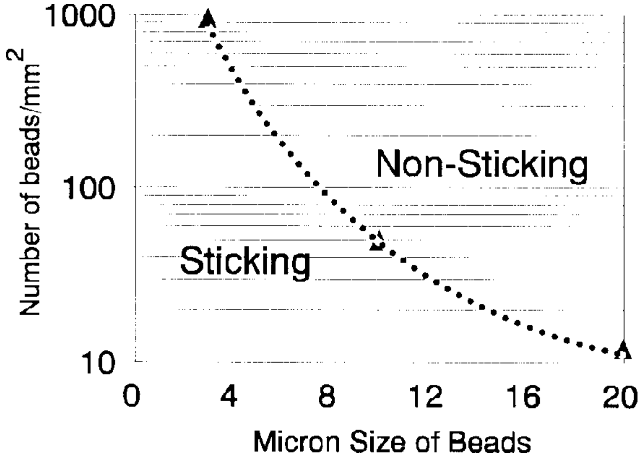


Figure 4. Relationship between bead size and number of beads required in Approval receiver.

A laser thermal process is a kind of brute force approach to imaging. The sensitivity to light is about a factor of 1 million less than for silver halide film. Figure 3 illustrates the difference between amplified and essentially unamplified direct write systems.

In effect, the only amplification in the Approval process is electronic. This is why the system is robust and reliable. Electronic amplification can be almost noise free. In practice, it has been found that two Approval systems miles apart, but fed from a common data stream, give identical proofs. In the same way, the machine delivers the same proof from day to day, week to week, and month to month.

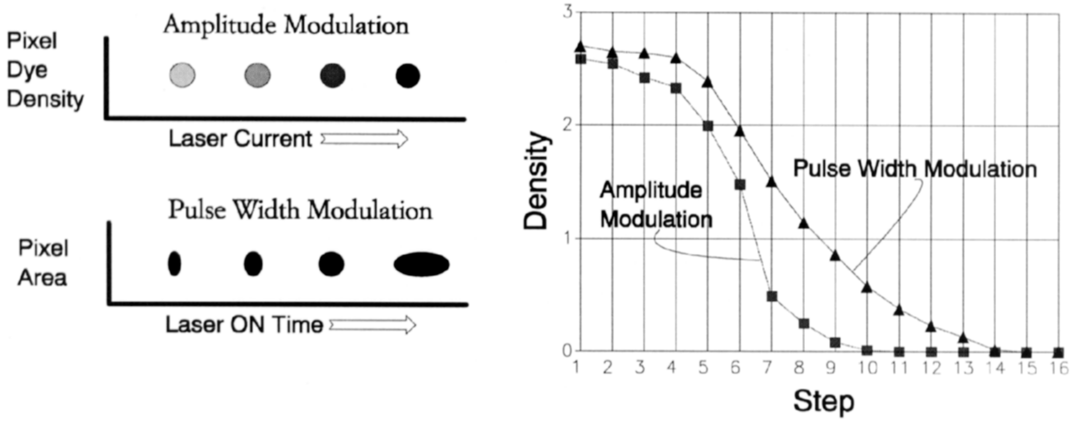
The spacer beads in the Approval intermediate receiver are interesting. When work first began on the project, there were no beads and the images were very blotchy with areas of low or no density and other areas of very high density. We rapidly realized that in areas of contact between the donor and receiver, two problems occured. In one, the contact provided an additional heat sink that lowered the efficiency of the process and gave low density. In the other, the contact area acted like hot melt glue, and when the donor and receiver were separated, the entire dye layer was ripped off its support and transferred to the receiver. A systematic study of the problem showed that both the number and size of beads was important. The effect is similar to tent poles. If you have a few tall poles, the tent won't touch the ground. If the poles are short, many more are needed. This relationship is shown in Fig. 4.

Another interesting mechanistic detail of laser thermal dye transfer is the chaotic threshold between sublimation and ablation. When irradiating through the base of the film, most of the heat is generated at the bottom of the dye layer. When writing with a constant laser power and constant drum speed, i.e., line exposures, at low power, sublimation alone is found as evidenced by photomicrographs of the surface of the dye layer that show a simple decrease in the level of the layer in the laser path. As the power is increased, long bubbles resembling sausages start to appear under the surface of the dye layer. As the power is increased still more, occasional, randomly positioned vent holes appear in the bubbles. Inspection of the receiver shows a high concentration of dye opposite the vent holes. As power increases, the number of vent holes also increases, until at high power the whole layer is blown open with essentially all the dye transferred to the receiver. At the transition point, a sharp increase occurs in dye density, which makes it hard to control the printed dye level. One way to control this problem is to shift from amplitude to pulse width modulation of the laser. Figure 5 illustrates the idea.

As shown in Fig. 5, amplitude modulation is represented by an increasing laser current and, therefore, increasing laser energy that results in higher dye densities all in the same area. In pulse width or frequency modulation, the pixel is essentially subdivided into micropixels by varying the laser on-time. Thus, the pixel varies in area, but the density of the micropixel transferred is always the same maximum high density. This means no transition region exists from sublimation to ablation; all the pixels are created by ablation, but they vary in area. As Fig. 5(b) shows, this results in a smoother, more gradual tone scale.

Color Separations

Another product in the Kodak line is the Kodak Professional Direct Image thermal recording film. A schematic of this film is shown in Fig. 6. On exposure to the diode laser beam, the infrared dye absorbs the radiation and heats the layer to the point where ablation occurs. A vacuum apparatus collects and filters off the dye "smoke."



(a) (b)

Figure 5. (a) Laser pulse modulation schemes for direct laser thermal imaging, (b) Characteristic curves for each modulation scheme.

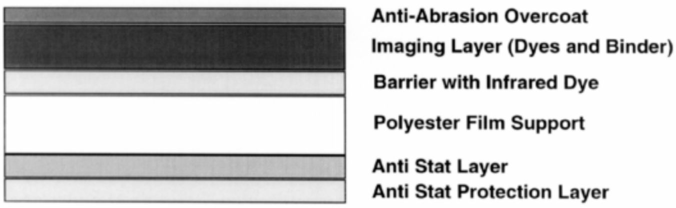


Figure 6. Kodak Professional Direct Image thermal recording film.

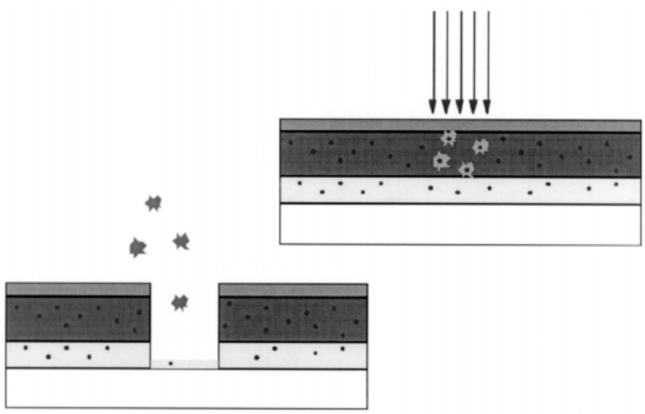


Figure 7. Dye removal mechanism.

The dye removal mechanism is illustrated schematically in Fig. 7. The scanning electron micrograph in Fig. 8 shows a 50% checkerboard exposure. The removal of the dye layer is obvious.

Dr. Daniel Haas of Eastman Kodak Research Labs., calculated the temperatures generated by the moving laser beam as shown in Fig. 9. The contour plot emphasizes the steep temperature profile at the edges of the laser beam. A drop of 100 degrees is only about 1 μm in distance.

It is unlikely that the dye layer actually reaches the high temperatures found in the calculation. Ablation and sublimation of the dye must carry away considerable heat and limit the actual temperature rise. A model of the heat flow including the effect of a second nearby laser spot on the temperature profile has been presented by Zumsteg and Hunt[5] of DuPont. Their results show that the second laser spot essentially "pulls" the center of the heat of the first laser toward the second laser.

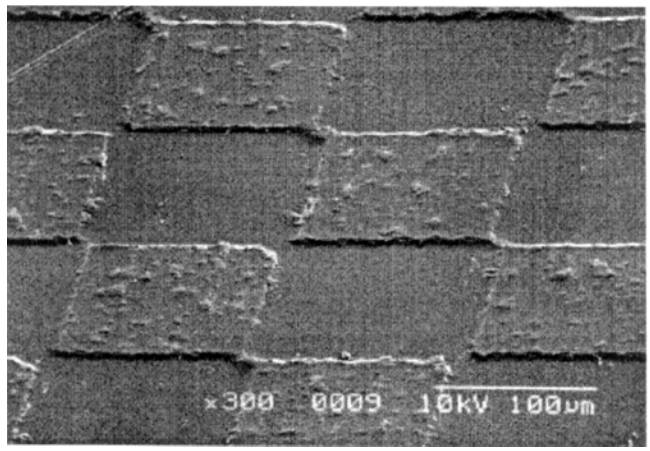


Figure 8. SEM of laser dye removal image.

The behavior of the direct write film with exposure has been studied. A target was prepared of 50% checkerboards at different pixel sizes from very large to single pixel as illustrated in Fig. 10. The laser thermal film was exposed to the target at different drum rpm rates, which correspond to different energy per area exposures. Then the percent dot area was measured and plotted as shown in Fig. 11 to allow estimation of the optimum exposure. The graph shows that at heavy overexposure too much dye is removed and the dot area shrinks. At underexposure, not enough dye is removed and the dot area is large. In the middle exposure, about 425 mJ/cm^2, the dot area remains constant as a function of cell size. This may be considered a measure of optimum exposure for this particular experimental film.

Litho Plates

Another laser thermal product of a slightly different mechanism is the Kodak Professional Direct Image thermal printing plate. In this product the laser thermal heat generates an acid that changes the solubility of the ink receptive polymer layer in the alkaline developer. The process is illustrated in Fig. 12. In the early stages of the work with the Kodak laser thermal litho plate, it was thought that the plate would deliver a serviceable image but fall short of the highest levels of image quality because the exposure was done with an 1800 dpi machine, which is far less than the 4000 dpi used for film image setters. However, to our surprise the plate delivered images of higher

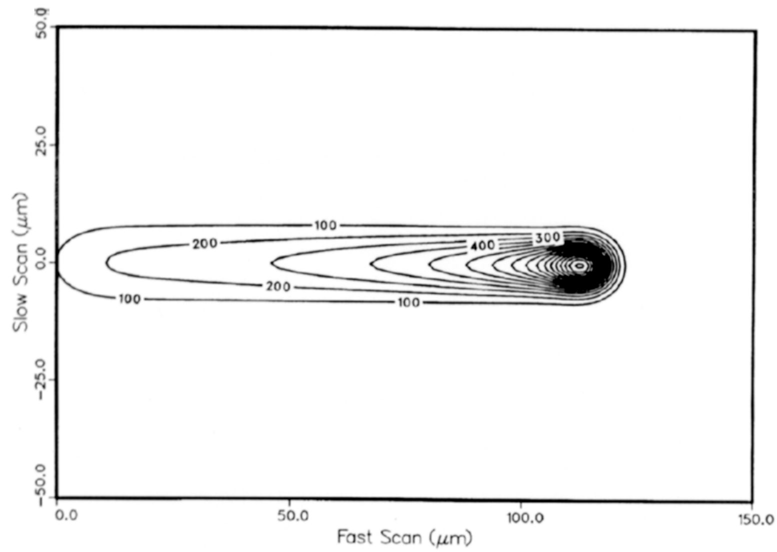


Figure 9. Contour plot of the temperature generated in thermal imaging media by a moving laser beam.

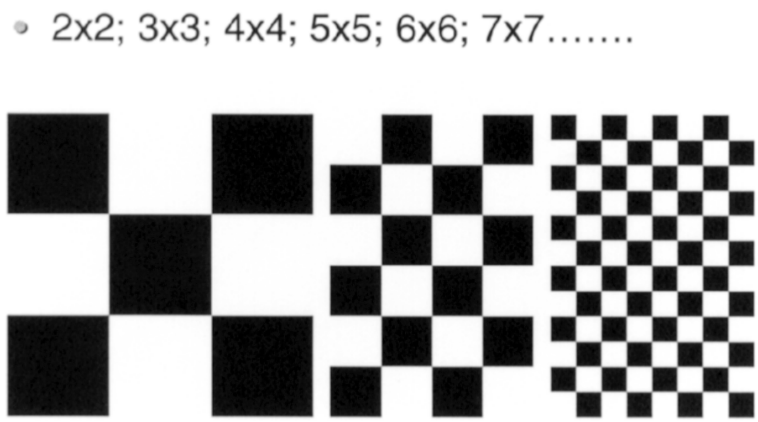


Figure 10. 50% dot target.

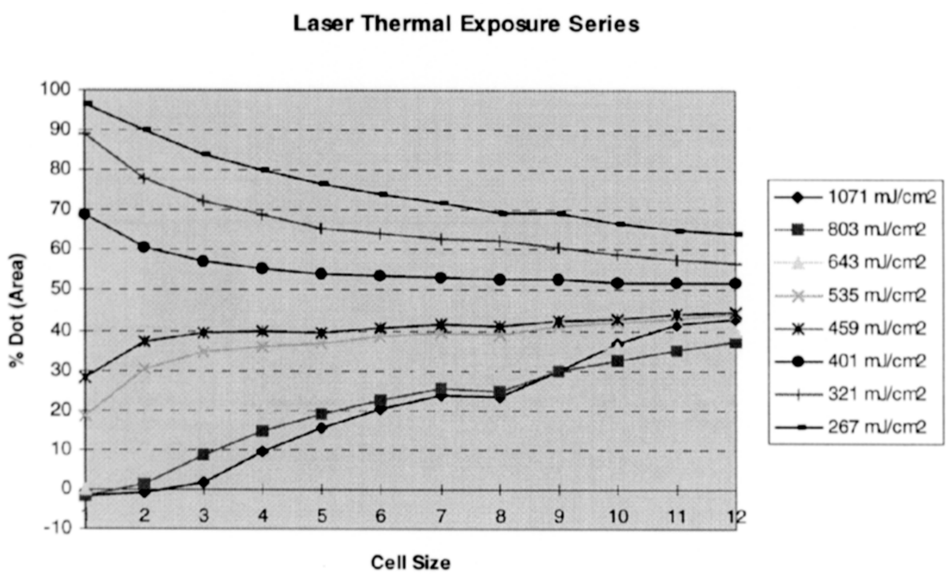


Figure 11. Laser thermal exposure series used to estimate optimum exposure.

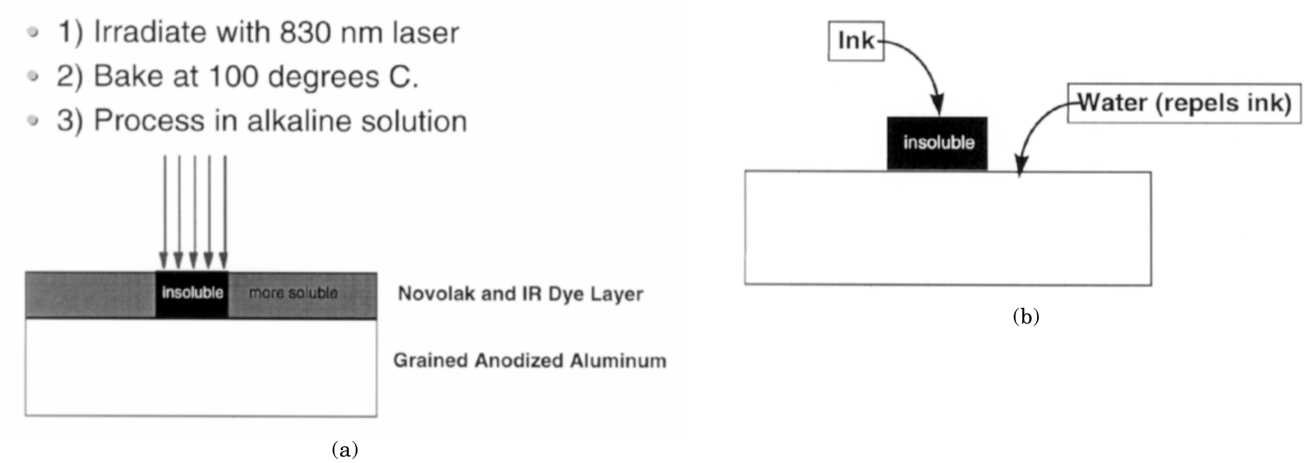


Figure 12. Kodak Professional Direct Image printing plate: (a) schematic of imaging process, (b) function on the printing press.

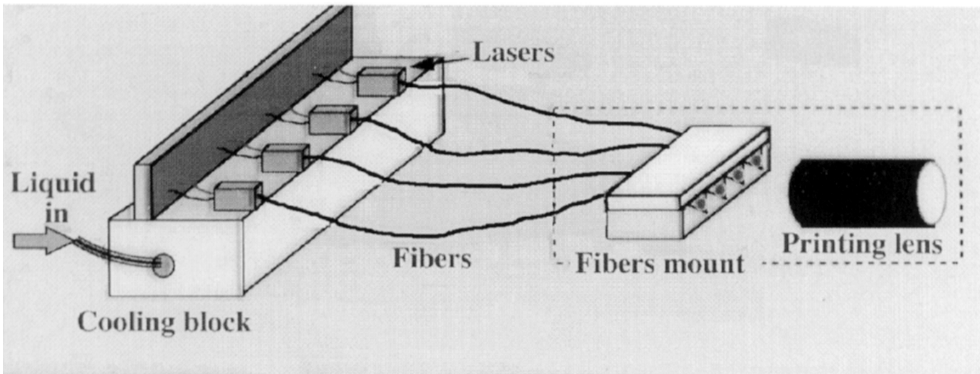


Figure 13. Fiber optic based laser printhead. The indicated cooling liquid is an experimental option.

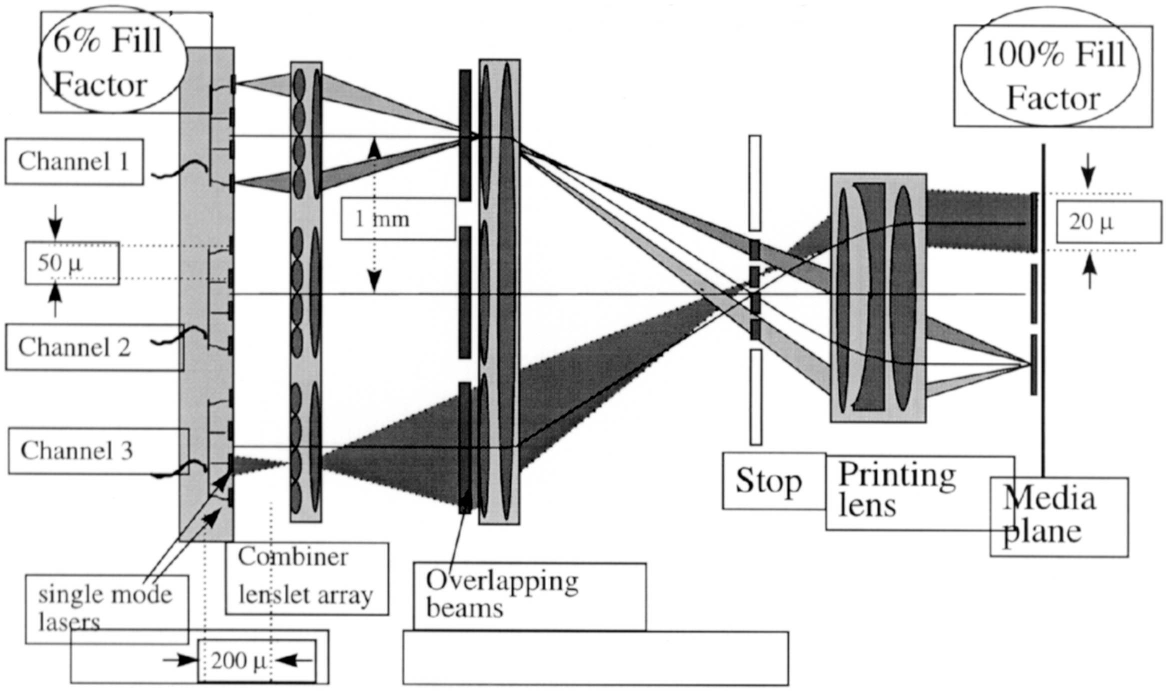


Figure 14. 10-channel printhead using an independently modulated laser diode array.

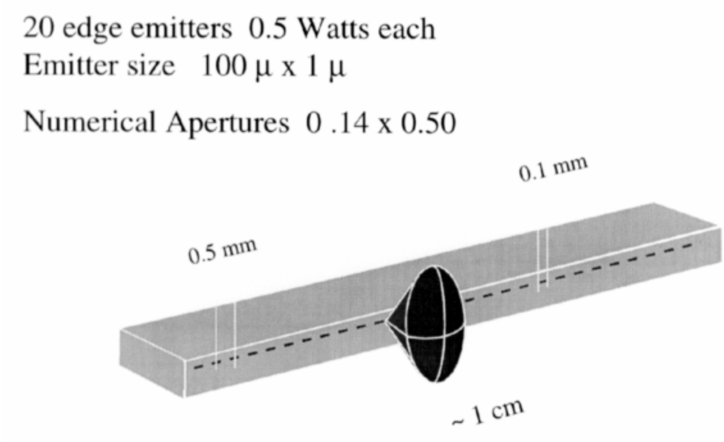


Figure 15. Laser diode "bar."

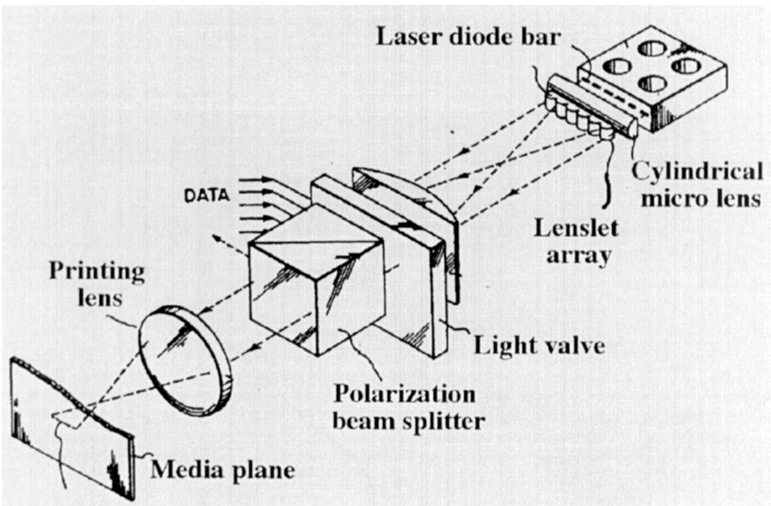


Figure 16. The CREO printhead.

quality than those found with conventional film-burning systems, despite the limited 1800-dpi resolution. Evidently, the MTF loss in exposing a conventional litho plate through film is larger than thought, and direct creation of a first-generation image on the plate gives the sharpest possible image. This suggests a bright future for laser thermal direct-to-plate systems.

Another direct write laser thermal printing plate is being sold by the Presstek Company. This plate is used in the driographic printing process, where no fountain solution is used. A surface of 3-μm thick polydimethylsiloxane is coated over a thin (30 nm) titanium film on a polyester support. When exposed to the focused beam of an infrared diode laser, the titanium film debonds from the silicone rubber overcoat. The layer is then rubbed with a cloth to remove the loosened rubber, exposing the polyester below which takes ink in the printing process. The remaining silicone rubber absorbs enough solvent from the ink to provide a slippery, ink repellent surface. Many of the mechanistic details of the process are found in an article by Hare, et al.[6]

Lasers

Several kinds of diode lasers have been used for laser thermal systems. Single-mode lasers for imaging directly on the film plane have been developed by CREO. The Kodak Approval system uses single lasers, each with a fiber optic cable to carry the light to the film plane, as diagrammed in Figs. 13 through 15. The CREO Company uses an unmodulated laser bar as a light source with an external modulator to create the pixels on the media plane (Fig. 16).

The Future

In the future, application may be found for the new fiber lasers that take the light from a bar laser and convert it into a longer wavelength single-mode spot of high wattage. Such a laser would allow the production of single flying spot machines with enough power for laser thermal processes.

Future media for the graphic arts industry will probably concentrate on two areas—direct to plate and direct color proofing. Direct color proofing will be important because direct to plate eliminates the film image and without the film a conventional color proof cannot be made. Several companies have announced work on direct-to-plate media that do not require processing, which would open the possibility of exposing the printing plates directly on the press. We can expect to see automated printing press systems in the future that look more like a copier. Copier-type printers are still the cheapest way to make less than a few hundred copies of a document, but when more than about 300 copies are desired, the price of ink on paper makes the printing press the logical choice.

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