From Die- to Dye-Cutting: Bringing Cheap Laser Cutting Power to Printing Terminals

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Abstract

Laser diodes are not normally able to cut paper, since plain paper does not absorb light in the visible and in the Near Infrared. However, it is possible to make paper locally absorbing to the Near Infrared laser light by ink-jetting an ink formulated from Near Infrared absorbing dyes allowing laser cutting using a 1 W diode. Several applications of this technology are presented and discussed, with cutting speeds up to several tens of meters per minutes.

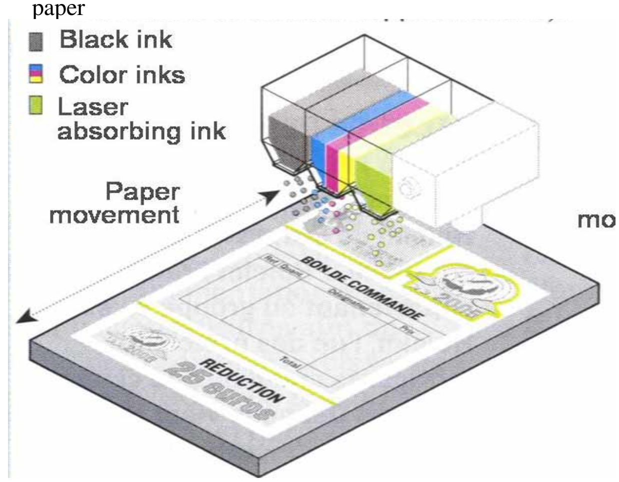
Introduction

Optical technologies have played a major role in the development of numerous printing technologies. Lasers are used for photofinishing applications, and laser diodes are key parts of laser printers. Paper and cardboard are frequently cut to shape using CO_2 lasers in the so-called paper conversion industry. Recently, we reported an innovative use of laser diodes in the area of Digital Printing.[1,2,3,4] This technology adds to a number of applications of laser diodes for material processing.[5]

Our innovation consists in a laser-based process that allows cutting paper in an inkjet printer by using a laser diode. By itself, the laser diode cannot cut the paper, since the Near InfraRed (NIR) light emitted by the laser is not absorbed by white paper. The innovation consists in ink-jetting the lines to be cut with a special Infrared absorbing ink that penetrates deep into the paper, and then cutting the paper with a laser diode. Experimental demonstrations have been performed. Cutting speeds of several meters per minutes can be achieved using low cost single laser diodes with powers of one watt. Easy-folding lines can be created by adjusting the speed and power of the laser.

The operation of such a device is sketched on Fig. 1. In a first step, inks are ink-jetted on the paper. These inks comprise not only the conventional graphical inks, but also an additional ink that absorbs the NIR radiations of the laser. In contrast to the graphical inks that remain on the very surface of the paper, the absorbing ink should penetrate all through the paper, in order to make the paper absorbing in its bulk. Lines of this absorbing ink are printed along the paths to be cut or scored. This step is performed in raster mode: the inkjet heads move at constant speed laterally over the paper, and fire their inks through their nozzle arrays when appropriate. In this way, a given surface of the paper is treated at each carriage pass. The second step consists in laser-cutting or scoring. This step is performed in vector mode: the laser is displaced along the lines to be cut or scored, by combining the movement of the head carriage, and the front and back movement of the paper tray. For a given laser power, the displacement speed should be adjusted to obtain either a complete cut, or an easy folding line.

1) First step: graphic inks and IR absorbing ink are jetted on paper



2) Second step: the beam follows the IR absorbing lines

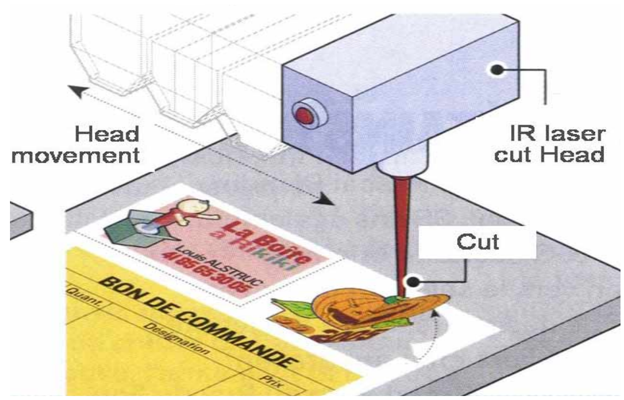


Figure 1: Sketch of our innovative laser-based cutting process

While initial experiments reported the demonstration of the laser-diode ability to cut and score paper that is properly inked, and established the necessity of this inking, the inking step had been performed manually. In this paper, it is shown that the inking step of the NIR ink can be performed using conventional ink-jetting heads. In addition, different dyes are investigated, and the optical properties of the inked paper are investigated experimentally and discussed. The comparison with conventional CO_2 laser cutting technology, and with different mechanical cutting techniques, is also presented.

Demonstration of Innovation

NIR dyes that are nearly transparent in the visible range can be used as additives in plastics for laser welding [6], or for security marking (verification and authentication) and other imaging applications. Depending on their chemical properties, theses dyes are soluble in different types of solvents. In our approach, water-soluble dyes were preferred because of better compatibility with all types of print heads, and safety considerations. A select set of water soluble NIR dyes (SDA8700, SDA8680, SDA1910 and SDB1822) were supplied by H. W. Sands Corp. consistent with the wavelength of the laser diode.

The inks were formulated by diluting the NIR dyes into water + 2-propanol (80/20 v/v). The 2-propanol was added in order to allow better ink penetration in the paper, and also because it was safe from any health hazard. Inks were prepared with 1.5mg/ml of dye in the water + 2-propanol solvent.

To perform the broadest demonstration of ink-jettability of NIR absorbing inks Thermal Inkjet systems were used due to their compatibility with aqueous ink systems. Experiments were performed using both a Hewlett-Packard 1600C printer, and a Hewlett Packard DeskJet 695C printer. Old models of printers were preferred to new models because cartridges were easier to refill, and also because older printers had droplet volumes larger that new ones, consistent with the need to ink into the depth of paper.

Office grade paper 80g/m^2 was inked using the HP printers with their black ink cartridges cleansed and refilled with the NIR absorbing inks described above. The printer was addressed through the drivers provided by the printer manufacturer. As a consequence, no direct control of drop size, drop number, or any relevant nozzle parameter, could be achieved.

The reflection and transmission of white paper and of paper ink-jetted using an ink formulated using SDA8700 dye at a concentration of 1.5mg/ml were measured using a Varian spectrophotometer equipped with an integrating sphere.

Results and Discussion

Fig. 2 indicates the reflection and transmission of white paper, and of paper ink-jetted using an ink formulated using SDA8700 dye at a concentration of 1.5mg/ml. It can be seen that though white paper reflects nearly 80% of the incoming light, about 20% is transmitted. Reflection and transmission do not occur in specular directions, but in a diffused manner.

On the recto of the inked paper, a significant decrease of the diffuse reflection coefficient is observed in a Near Infrared band. The decrease is significant on the verso, nut not as much pronounced. The transmission coefficient is measured to be nearly the same in both case, and nearly all transmission is quenched. In the visible range, a pale greenish-grayish appearance is noted on the recto, and faintly observed on the verso.

These results suggest that the penetration of the ink through the paper is not complete. However, it far exceeds the penetration of conventional graphics ink, which remains on one side of the paper. Different settings of the printer have been tried in order to increase the absorption. For example, the "premium paper" option has been tried.

Fig. 3 represents the supplementary absorption brought by the ink. If A_0 is the absorption $1\text{-}R_0\text{-}T_0$ brought by the paper at the given wavelength, the supplementary absorption is expressed as a function of the reflectivity and transmittivity R and T of the inked paper by: $A= 1\text{-}R\text{-}T\text{-}A_0$. It can be seen on Fig. 3 that the "premium paper" option indeed affects the spectral response of the inked paper. It adds or enhances a supplementary peak in the absorption around 940 nm. The reflection coefficient on the verso is smaller with the "premium paper" option. This indicates that this driver setting is not favorable to a better ink penetration.

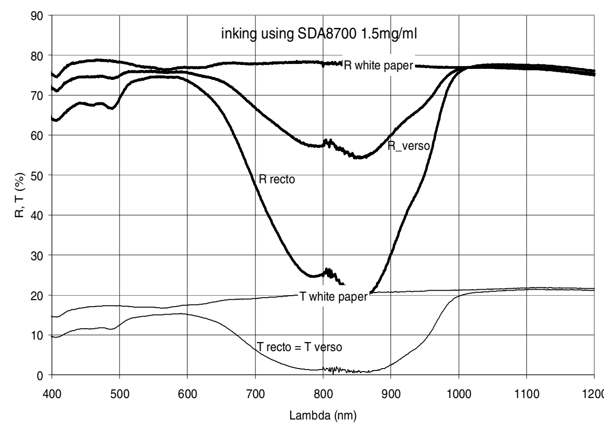


Figure 2: Reflection and transmission coefficient measured on white paper and on a paper ink-jetted with an ink formulated with SDA8700 at 1.5mg/ml. The values of R for the inked paper are given both for light incident on recto and on verso side of the paper. The values of T measured for recto and verso are identical.

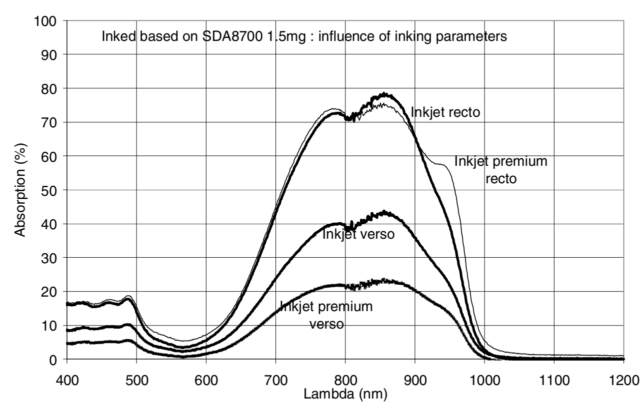
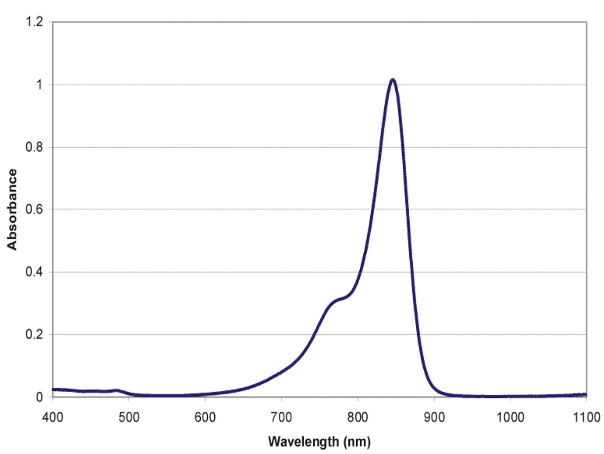


Figure 3: *Absorption brought by the ink measured on white paper ink-jetted with an ink formulated with SDA8700 at 1.5mg/ml. Two types of inkjet settings have been used: normal quality, and premium quality.*

The absorbance spectrum of the SDA 8700 dye, as supplied by H. W. Sands Corp. is shown in Fig. 4. Dye absorbance spectra are usually obtained from a dilute solution of the dye. In this case the spectrum was obtained from a dilute methanol solution. Note that the spectral response of the inked paper is much broader than the absorbance measured in solution. However, the peaks visible on Fig. 4, around 775nm and 845nm, are present on the response of the inked paper. It is remarkable that though the absorbances of the two peaks differ by a factor of 3 in solution, the absorption measured on the paper is nearly equivalent. Also, the absorption peak on the paper is much stronger than in solution based on the effective concentration. The absorption efficiency is 80% of its maximum efficiency in the 740 to 900nm range, while the absorption in solution is reported to drop by a factor larger than 50 at 900nm. In the visible range, the slight increase in absorbance below 500nm pictured on Fig. 4 yields significant visible absorption on the inked paper.

Fig 4: *Absorbance spectrum of H. W. Sands SDA8700 in methanol*



These differences are related to the different propagation regimes of light between a solution and paper. Strong diffusion occurs in the paper, and long paths related to multiple may account for the observed behavior. The absorption in diffuse media, including paper, is frequently investigated through the Kubelka-Munk formalism, or more recent approaches that refine this method. Such approaches are not used here, but we established that though the spectral response in solution of a dye may be a useful guideline to make an absorbing ink, significant differences appear between the optical characteristics of the dye and the properties of the inked paper.

The spectral response of paper inked with three different inks made using different dyes is given on Fig. 5. All the inks were formulated using a dye concentration of 1.5mg/ml. All these inks are adapted to absorption around 820nm. Other dyes were tested, such as SDA1910, which gives absorption properties to paper in the 750 to 970 nm range. The visible appearance of paper ink-jetted with the different inks was observed on large areas of printed paper. Results are reported in Table I. Fine lines ink-jetted with these inks were very stealth.

Commercial Name	Visible appearance
SDA 8700	pale yellow
SDA 8680	pale grey
SDA 1910	pale red
SDB 1822	pale green

Table 1: *Visible appearance of large ink-jetted areas using inks made of different NIR dyes at a concentration of 1.5mg/ml.*

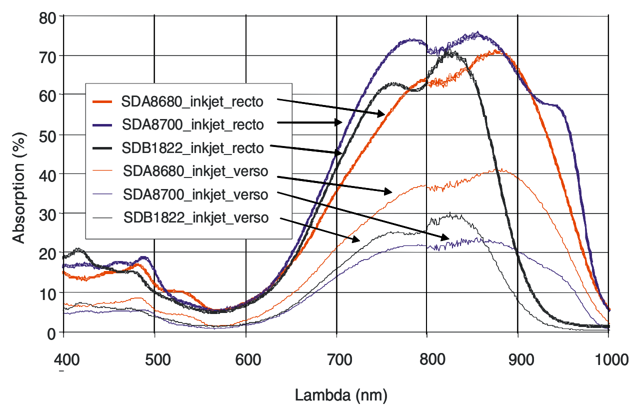


Fig 5: *Absorbance spectrum of H. W. Sands SDA8700 in methanol*

Conclusions on the Inkjettability of NIR Inks

We have established that NIR absorbing inks can be ink-jetted using the most restrictive technology in terms of ink, thermal inkjet. Different dyes have been tested successfully.

Ink penetration may still be optimized, as evidenced by the significant difference in absorption measured on the recto and verso. It is believed that increasing the absorption of the ink into the paper may require an increase in the amount of fluid jetted by the head. The inability to control the inkjet nozzles on commercial printers did not allow us to perform such experiments. Wetting agent may also increase ink penetration. By increasing ink penetration, it should be possible to increase the coupling efficiency of the laser with the inked paper, and possibly lower the concentration of dye required in the ink.

From Desktop to Industrial Applications

Desktop applications of this technology have been commented on in our recent work.[1,2,4] Their feasibility is supported by our demonstration of direct ink-jetting of NIR absorbing inks.

In addition, though less visible than desktop inkjet printing, a significant number of industrial applications include inkjet stations and require paper cutting. This is the case of wide format printing, and the label industry. These industrial sectors may benefit in the short term based on this innovation. Other sectors requiring paper cutting of complex shapes with easily reconfiguration ability may also adopt this technology. The ink-jetting step prior to the laser cutting can be easily performed using presently available industrial inkjet print engines. In such industrial applications, the use of commercially available 6W laser diodes yield a cutting rate between 9 and 19 m/min, according to the extrapolations of the cutting speeds we measured on our low power apparatus (see Figs. 6-7). With diode laser sources involving multiple emitters coupled into a single fiber, the cutting speed can be increased by a significant factor. At up to several tens m/min cutting speed, this technology may be attractive compared to CO2 cutting technology, since the source is more compact and requires lower cost mechanical movements. In addition, the source is very energy efficient, easier to cool, and has very long life.

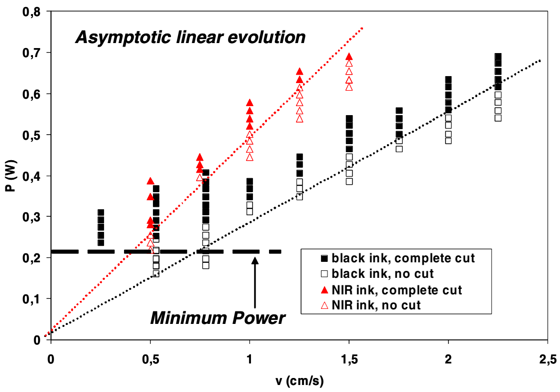


Fig 6: Threshold cutting speed obtained experimentally on paper inked with either NIR absorbing or black marker ink

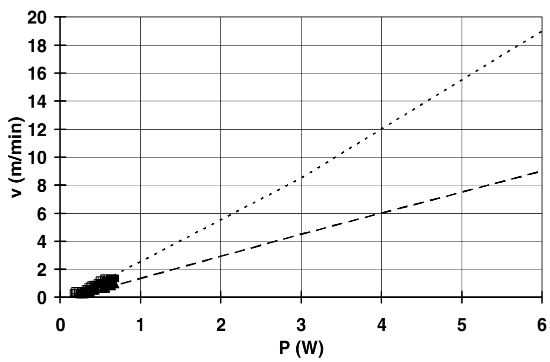


Fig 7: Asymptotic threshold cutting speed behavior for cutting speeds using laser diodes up to 6W

Conclusion

It has been demonstrated that significant absorption can be induced locally into bulk paper through an inkjet process using aqueous inks based on NIR dyes. The overall absorption of inked paper may not however be simply extrapolated from the absorbance measured on a solution of dye, presumably because diffusion within the paper is the main mechanism for light transport in the medium. The inking allows paper to be cut using a laser diode. This opens significant fields of applications in both industrial and personal printers.

References

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[6] See www.clearweld.com

Author Biography

Olivier ACHER is Chief Scientist at CEA. He graduated from the Ecole Polytechnique (1986) and obtained his PhD on optoelectronic materials and devices. He created in CEA a microwave and magnetic materials laboratory directed toward various applications. He is the author of 70 refereed papers, 20 patents, 3 licensing actions. He was awarded the IBM Young Scientist Award in 1990, the "Grand Prix Général Ferrié" in 2002, and nominated for the Leibinger Laser Innovation Prize in 2006.