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Comparison of Argon-Ion, Copper-Vapor, and Frequency-Doubled Neodymium:Yttrium Aluminum Garnet (ND:YAG) Lasers for Latent Fingerprint Development

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ABSTRACT: Argon-ion, copper-vapor, and frequency-doubled neodymium: yttrium aluminum garnet (Nd: YAG) lasers have been examined for efficiency in latent fingerprint detection. All three types of laser are found to be effective. Argon-ion lasers have the greatest power and range of useful wavelengths while frequency-doubled Nd: YAG lasers offer crime scene capability. On rare occasions latent prints observable under the argon-ion laser are not visually discernible under the Nd: YAG laser, but can be located with a sensitive television camera. Once located, photography of such prints is straightforward.

KEYWORDS: criminalistics, fingerprints, lasers, argon-ion laser, copper-vapor laser, frequency-doubled Nd: YAG laser, crime scene investigation

In the past, laser latent fingerprint development exclusively used argon (Ar) lasers. Recently, however, copper-vapor lasers have started to find use in fingerprint detection as well and in the last year, frequency-doubled neodymium: yttrium aluminum garnet (Nd: YAG) lasers have emerged on the fingerprint scene. It thus is timely to assess the efficacy of these types of laser for the development of latent fingerprints.

The Ar lasers used to date for latent fingerprint work have been either 5- or 20-W (all-lines blue-green) instruments. The 20-W lasers have large electrical current and water cooling requirements and are thus strictly laboratory instruments. The smaller (5-W) Ar lasers can in principle be powered by large portable generators and can use household water for cooling, but are nonetheless not easily used for crime scene work. The copper-vapor laser has electrical and cooling requirements similar to those of the smaller Ar laser. It is bulky, however, and thus not readily portable either. The frequency-doubled Nd: YAG laser (Laser Printfinder, Laser Photonics, Inc.), on the other hand, is compact, requires no external water for cooling, and operates on ordinary household current. It may even be operated with a car battery. This laser, therefore, is uniquely suited for crime scene work. Since lasers are expensive, a crime scene laser must also be competitive in a laboratory setting, however, in terms of its ability to develop weak latent fingerprints.

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Laser Operation Characteristics

Argon-Ion Laser

The argon-ion lasers used by law enforcement agencies for latent fingerprint development usually deliver either about 20 or 5 W CW (continuous) in the blue-green at 457.9, 465.8, 472.7, 476.5, 488.0, 496.5, 501.7, and 514.5 nm, the 488- and 514.5-nm lines being the main ones. Usually, the Ar laser is operated in the all-lines mode for fingerprint work. If strong background fluorescence occurs, however, producing contrast problems, it is advantageous to operate the laser at a single line. The 514.5-nm operation is best suited for detection by inherent fingerprint fluorescence [*1*], dusting with rhodamine 6G-based powders, and staining (evaporative or solution) with rhodamine 6G [*2*]. The 488-nm operation is best suited to detection by the ninhydrin/zinc chloride procedure [*3*]. These three general approaches form the present routine procedures for latent fingerprint development. Ar lasers can also operate in the near ultraviolet at about 351 and 363 nm. Although this mode of operation can be effective [*4,5*] it is not generally used at present in case work. Procedures that call for ultraviolet illumination and are designed for surfaces such as woods, brown paper, and cardboard, which fluoresce strongly under blue-green illumination, thus being difficult to deal with, have been developed recently, however [*6*].

Copper-Vapor Laser

This laser is pulsed, operating at about 5 kHz, and delivers lines at 510 and 578 nm. The latter line is presently not used for fingerprint development and is quenched by an intracavity dichroic filter. The pulse energy at 510 nm is about 1.4 mJ with pulse duration of about 30 ns. The laser thus delivers about 7 W of average power at 510 nm.

Frequency-Doubled Nd: YAG Laser

This laser, which normally operates at 1064 nm, is equipped with a frequency-doubling crystal that converts the laser light to 532 nm. The laser is pulsed at 20 Hz. The pulse energy at 532 nm is about 7 mJ, with pulse duration of about 10 ns. The pulse power is thus roughly 700 kW and the laser power averaged over many pulses is about 140 mW.

Comparison of Lasers

The detectability of latent fingerprints was studied using Spectra-Physics models 171-09 and 164-05 Ar lasers, a Plasma Kinetics model 151 copper-vapor laser, and the Laser Printfinder of Laser Photonics, Inc. This system consists of a Nd:YAG laser with the above described characteristics, an image-intensified television camera, and a television monitor.

The copper-vapor laser was utilized during a visit to Plasma Kinetics and during a workshop at the Tallahassee Regional Crime Laboratory of the Florida Department of Law Enforcement. The author's laboratory (Center for Forensic Studies, Texas Tech University) is equipped with a Spectra Physics Model 164-05 Ar laser. Spectra Physics and Laser Photonics have donated a Model 171-09 Ar laser and a Laser Printfinder, respectively, to the author's laboratory.

Fingerprint detection by inherent fingerprint fluorescence, dusting with magnetic powder blended with rhodamine 6G, dusting with Mars Red, vapor, and solution staining with rhodamine 6G, and ninhydrin/zinc chloride were compared under the copper vapor and Ar laser. Fingerprint detectability was found to be essentially the same under the copper-vapor laser as under the Ar laser operating at 514.5 nm, when the average powers and illumination spot sizes were equal. At a given plasma tube current, the Ar laser, of course, delivers over twice the power all-lines than at 514.5 nm. Thus, the Ar laser is generally operated all-lines unless contrast dictates 488- or 514.5-nm operation.

At first glance, the frequency-doubled Nd:YAG laser appears grossly underpowered for fingerprint work, particularly when its average 140-mW output is compared with the 20-W output of a large Ar laser. To understand why the frequency-doubled Nd:YAG laser is nonetheless quite effective for latent fingerprint development, we consider the detection of fingerprint fluorescence by visual inspection as well as photography. We start out by examining the visual perception of the brightness of the Nd:YAG laser beam expanded to illuminate an area of about 127 mm (5 in.) in diameter (typical of illumination spot size for latent fingerprint detection). The human eye cannot resolve times less than 0.025 s. A pulsed laser operating at 40 Hz will thus appear CW to the eye. Even at 20 Hz, the laser will seem nearly CW, with only a relatively minor flicker perceptible. If, in addition, the power per pulse is large, as in the Nd:YAG laser, so that each pulse causes a large visual stimulus, then an increase in pulse repetition rate becomes a matter of diminishing visual return because of the logarithmic nature of vision. As a result, the Nd:YAG laser's light appears to the eye considerably brighter than it actually is. An Ar laser operating at 514.5 nm with about 750 mW gives equal perception of brightness as the 140-mW Nd:YAG laser output, when equal (127-mm [5-in.] diameter) areas are illuminated.

We next turn our attention to the visual perception of latent fingerprint fluorescence under laser illumination. As two representative examples of what one expect to generally encounter in case work, we considered a fingerprint on paper developed by its inherent fluorescence and a fingerprint, also on paper, developed by magnetic powder blended with rhodamine

FIG. 1—*Latent print on paper developed by frequency-doubled Nd: YAG laser (inherent fingerprint fluorescence).*

6G in the proportion 10 mg of rhodamine to 5 g of fine iron filings. The former print showed comparably bright fluorescence when illuminated by about 2 W of all-lines blue-green Ar laser light and the 140 mW of the Nd:YAG laser (equal illumination areas). Photographs of the print under the Nd:YAG and Ar-laser are shown in Figs. 1 and 2, respectively. The most noteworthy feature in comparing these two figures is the background fluorescence which tends to obliterate the print in Fig. 2. Increased Ar laser all-lines illumination would not remedy the problem.

The print dusted with rhodamine 6G blended powder is shown in Figs. 3 and 4, respectively, under Nd:YAG and Ar all-lines 2-W illumination, which gave comparable brightness of fluorescence. Again, contrast is clearly a problem in Fig. 4. The same print, illuminated by less than 1 W of 514.5-nm Ar laser light (same illumination spot size), obtained without changing the Ar laser tube current is shown in Fig. 5 and shows much improved contrast.

Figures 1 to 5 clearly show that *fluorescence contrast, rather than laser power, is the critical issue in latent fingerprint detection.* Since the eye's response is logarithmic, and since the dark-adapted eye can sense very low light level, the Nd:YAG laser output is generally quite sufficient to detect fingerprints that are detected by Ar or copper-vapor laser. Fingerprints developed by ninhydrin/zinc chloride and fingerprints on reflective surfaces such as smooth metals and glass, when weak, will, however, elude visual observation under the Nd:YAG laser while still observable to the eye under the Ar laser.

In the ninhydrin/zinc chloride case, the Nd:YAG laser is not well matched to the fluorescent aminoacid/ninhydrin/zinc chloride reaction product, which best responds to the 488-nm

FIG. 2—*Print of Fig. 1 developed by all-lines blue-green Ar laser excitation.*

FIG. 3—*Latent print dusted with rhodamine 6G-blended magnetic powder and developed by frequency-doubled Nd: YAG laser.*

line of the Ar laser. This shortcoming is remedied, however, by the ninhydrin analogue benzo(*f*)-ninhydrin, which is as good as ninhydrin in the conventional sense and which is spectroscopically tailored to the frequency-doubled Nd:YAG laser's 532-nm light once followed by zinc chloride treatment. Figure 6 demonstrates the improved detectability by benzo(*f*)ninhydrin/zinc chloride in concert with the frequency-doubled Nd: YAG laser (left half of the print) over ninhydrin/zinc chloride (right half). The benzo(*f*)ninhydrin/zinc chloride method for laser latent fingerprint development is described in detail in a separate paper [*7*].

When fingerprints are placed on specularly reflective surfaces (which, incidently, show little background luminescence), only light directly incident on the fingerprint ridge locations will cause luminescence. Scattered light however can cause fingerprint luminescence when paper, styrofoam, and other diffusely reflective surfaces are illuminated. Thus, latent prints on specularly reflective surfaces tend to show weak luminescence. However, such specularly reflective surfaces are generally treated by cyanoacrylate ester in concert with rhodamine 6G dusting or staining [*2*], and prints developed by these excellent methods fluoresce quite brightly. Thus, the frequency-doubled Nd:YAG laser, when used with the appropriate fingerprint development procedures [*8*], will only rarely fail when Ar lasers succeed in revealing latent prints to the eye by their fluorescence. To bring these rare latent prints into the realm of frequency-doubled Nd:YAG laser detection, the Laser Printfinder system is equipped with an image-intensified TV camera that exceeds the eye in the sensitivity. Once a print has been located by the TV camera, it can be photographed in the usual way. Figure 7 shows a latent print on glass photographed under the Ar laser. The print was readily visible under this illumination, but was not discernible by eye under Nd: YAG laser light. It did, however, show up under the TV camera

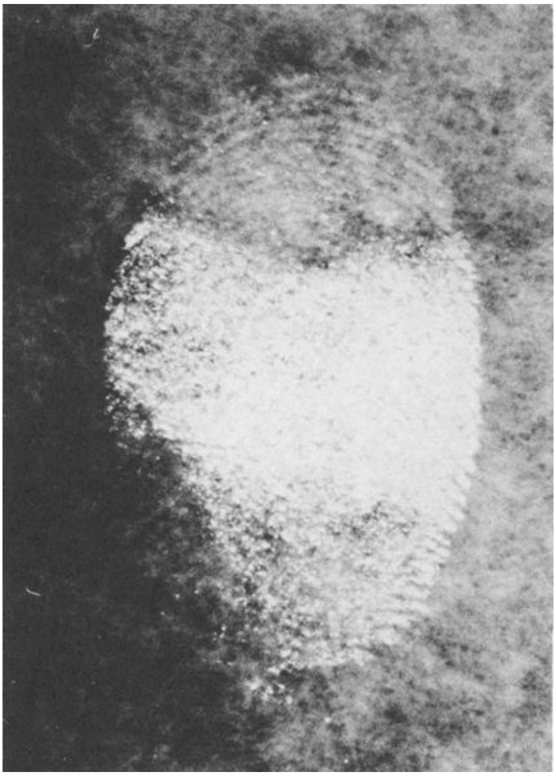

FIG. 4—*Print of Fig. 3 developed under all-lines blue-green Ar laser excitation.*

of the Laser Printfinder system. Figure 8 shows a section of the print on the TV screen. The print, once located by the TV camera, was photographed and is shown in Fig. 9.

Rhodamine B is a very good, indeed perhaps preferable, alternative to rhodamine 6G for blending of dusting powders as well as solution and evaporative staining. While the rhodamine B absorption is not as well matched to the frequency doubled Nd : YAG laser as the rhodamine 6G absorption, the fluorescence of the latter is not as well matched to the laser safety filter as that of the former. These features are indicated by the solution absorption and emission spectra of Fig. 10. The spectra were obtained using instrumentation and methods described previously [*9*].

Adhesive tapes often fluoresce strongly in the yellow. In these instances, the rhodamine dyes are not very effective and a dye that fluoresces strongly in the orange and red is preferable. 3,3′-diethyloxadicarbocyanine iodide (DODC) satisfies these criteria, as shown by the solution spectra of Fig. 11, and is effective in water solution for staining adhesive tapes such as masking and duct tape. However, DODC has the tendency to adhere strongly to these surfaces. Thus, the staining should be light and be followed by vigorous rinsing with water to remove excess dye. DODC is also effective for such staining in conventional sense. For example, Fig. 12 shows the room light development by DODC or a latent print on the sticky side of a piece of duct tape. The color of the development was a strong purple, rather than the dark blue one has with dyes such as crystal violet, and provided good contrast with the tape. Figure 13 shows the sensitivity one can obtain by combining DODC staining with Nd : YAG laser excitation. Figure 13*a* shows the room light photograph of a piece of masking tape stained with DODC. Under Nd : YAG laser excitation, a bright orange fluorescence was observed. This

FIG. 5—*Print of Fig. 3 developed under 514.5-nm Ar laser excitation.*

fluorescence development is shown in Fig. 13*b*. DODC in methanol solution also lends itself nicely to staining of smooth surfaces, particularly after cyanoacrylate fuming, much like rhodamine 6G. An example is given in Fig. 14. The surface is a piece of plastic (light switch), shown in room light after the treatment (Fig. 14*a*) and then under Nd:YAG laser excitation (Fig. 14*b*). DODC is generally useful when strong yellow background fluorescence is present. Because the DODC fluorescence extends well into the red, it may, in conjunction with a red filter, also improve contrast when orange background occurs. According to Fig. 11, DODC is not compatible with Ar or Cu-vapor lasers. For the Ar laser, the laser dye DCM is an effective counterpart to DODC, as indicated by the spectral data of Fig. 15. DCM is useful for dusting as well as solution and evaporative staining.

Discussion

As pointed out earlier, the Nd:YAG laser "fools" the eye into perceiving its light as about five times brighter than it really is. The photographic camera is not fooled, however, and photographic exposures are correspondingly longer under the Nd:YAG laser than under the Ar laser.

At a pulse repetition rate of 20 Hz, the flicker of the frequency-doubled Nd:YAG light, hence also flicker in fingerprint fluorescence, may cause headaches or nausea in some susceptible individuals. We have therefore investigated the possibility of increasing the pulse repetition rate of the laser to 40 Hz, at which point the laser's light appears continuous, rather than pulsed. This increased pulse rate should be achieved without radically shortening the life of the laser flashlamps, and without adding cooling requirements detrimental to portability. Accordingly, we have examined the fluorescence of fingerprints as well as the visual perception of the brightness of the Nd:YAG laser light under reduced pulse power.

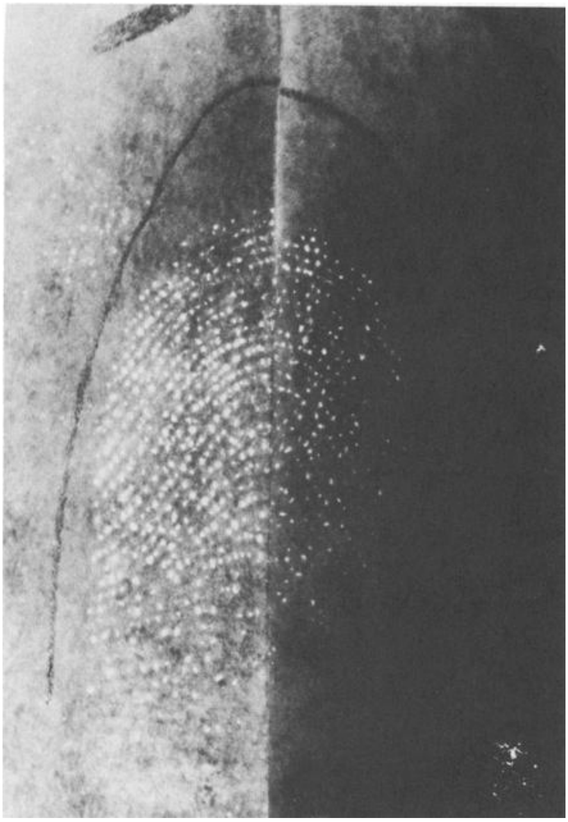

FIG. 6—*Latent print treated with benzo(f)ninhydrin* (left half) *and ninhydrin* (right half) *developed by frequency-doubled Nd: YAG laser after zinc chloride.*

With a neutral density filter of density 0.3, the laser power is reduced to half. To the eye, however, the laser light looks only slightly dimmer. For neutral density of 0.5, which reduces the laser power to about a third, however, a very definite reduction of laser intensity is perceived. Similarly, the fingerprint fluorescence reduction is only minimal for 0.3 neutral density. Because of the high intensity of the Nd:YAG laser pulses and the logarithmic response of the eye, the perception of the laser intensity is readily understood. The fingerprint fluorescence is weak, however, and one has to look for a different reason why it is only slightly reduced when the laser power is cut in half.

Figure 16 provides the answer. With unattenuated Nd:YAG laser illumination of an area about 50 cm^2 the fingerprint fluorescence intensity (measured with a Spectra Model 301 radiometer) is seen to saturate, that is, the fluorescence decrease is not linear with laser power attenuation. To understand the reason for this saturation, we consider the number of photons in one laser pulse. Seven millijoules of pulse energy corresponds roughly to 2×10^{16} photons/pulse. For a latent print strongly developed with rhodamine 6G, as was the print with which the data of Fig. 16 were measured, most of the laser light is absorbed by the rhodamine, that is, the optical density is roughly 1. The rhodamine 6G molar extinction coefficient is about 10^5. With these numbers, we can compute the number of rhodamine 6G molecules that would cover the 50-cm^2 area over which the 2×10^{16} photons in each laser pulse are distributed. We obtain 3×10^{16} molecules. Since almost all the laser photons are absorbed at optical density of 1 and since the pulse duration is not very much longer than the rhodamine radiative fluores-

FIG. 7—*Weak latent print on glass developed by all-lines blue-green Ar laser excitation. The print was visible to the eye under the Ar laser.*

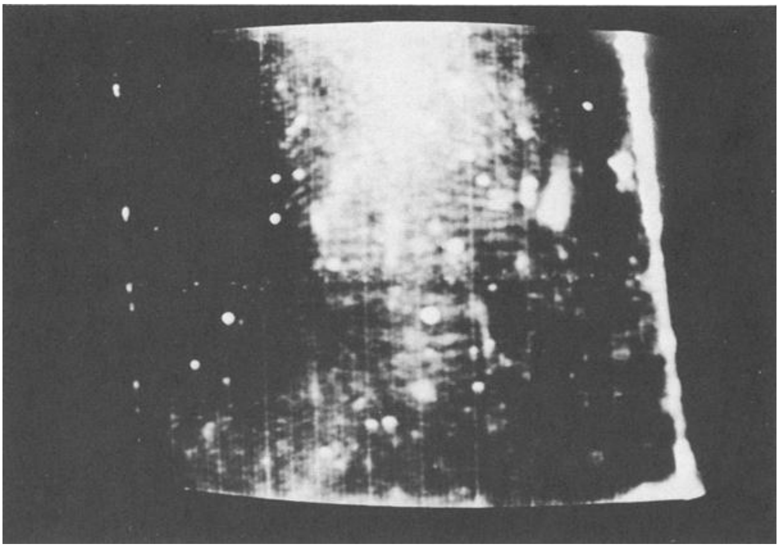

FIG. 8—*Section of the print of Fig. 7 under frequency-doubled Nd: YAG laser excitation and developed by TV camera. The print was not visible to the eye under the Nd: YAG laser.*

FIG. 9—*Print of Fig. 7 photographed under Nd: YAG laser excitation once located by the TV camera.*

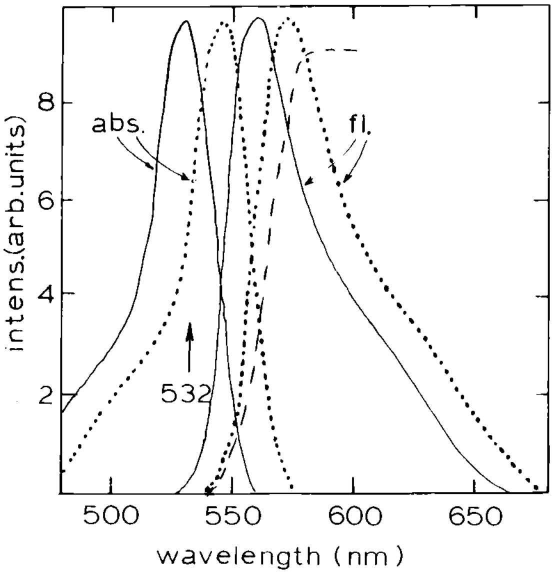

FIG. 10—*Absorption* (abs.) *and fluorescence* (fl.) *spectra of methanol solutions of rhodamine B* (dotted lines) *and rhodamine 6G* (solid lines). *The dashed curve denotes the transmission of the laser safety filter. The arrow shows the Nd: YAG laser wavelength.*

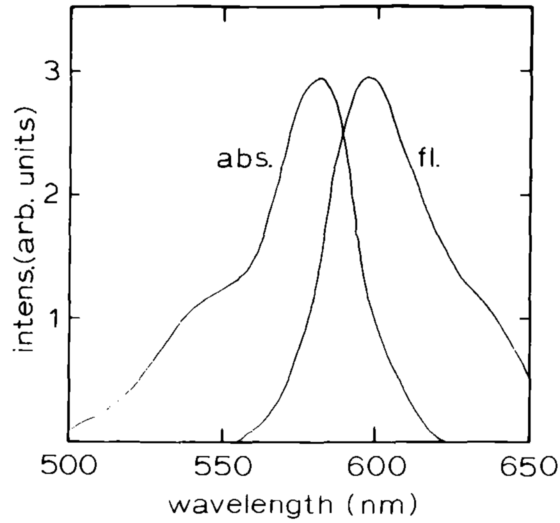

FIG. 11—*Absorption* (abs.) *and fluorescence* (fl.) *spectra of DODC in methanol solution.*

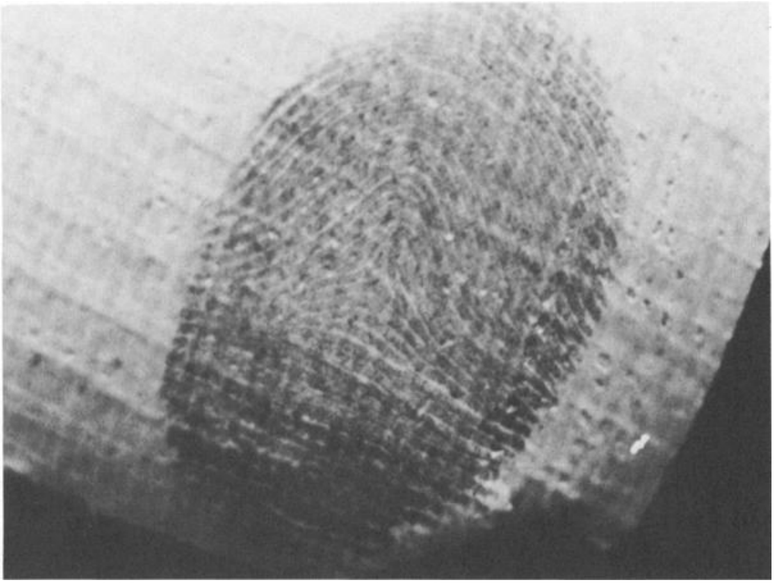

FIG. 12—*Room light photograph of fingerprint on sticky side of duct tape stained with a water solution of DODC.*

cence lifetime (around 6 ns), the computed numbers indicate that the bleaching regime is being reached. Thus, fluorescence saturation can be expected. One should therefore be able to increase the pulse rate at reduced pulse power without sacrifice of fingerprint detectability, and without detriment to flashlamp life or portability.

With regard to fingerprint detectability, all three types of laser discussed in this article are effective. The Ar laser has the greatest range of usable laser wavelengths, and easily pumps a dye laser as well, while the frequency-doubled Nd : YAG laser's portability means crime scene capability. The benzo(*f*)ninhydrin/zinc chloride treatment and the DODC staining demon-

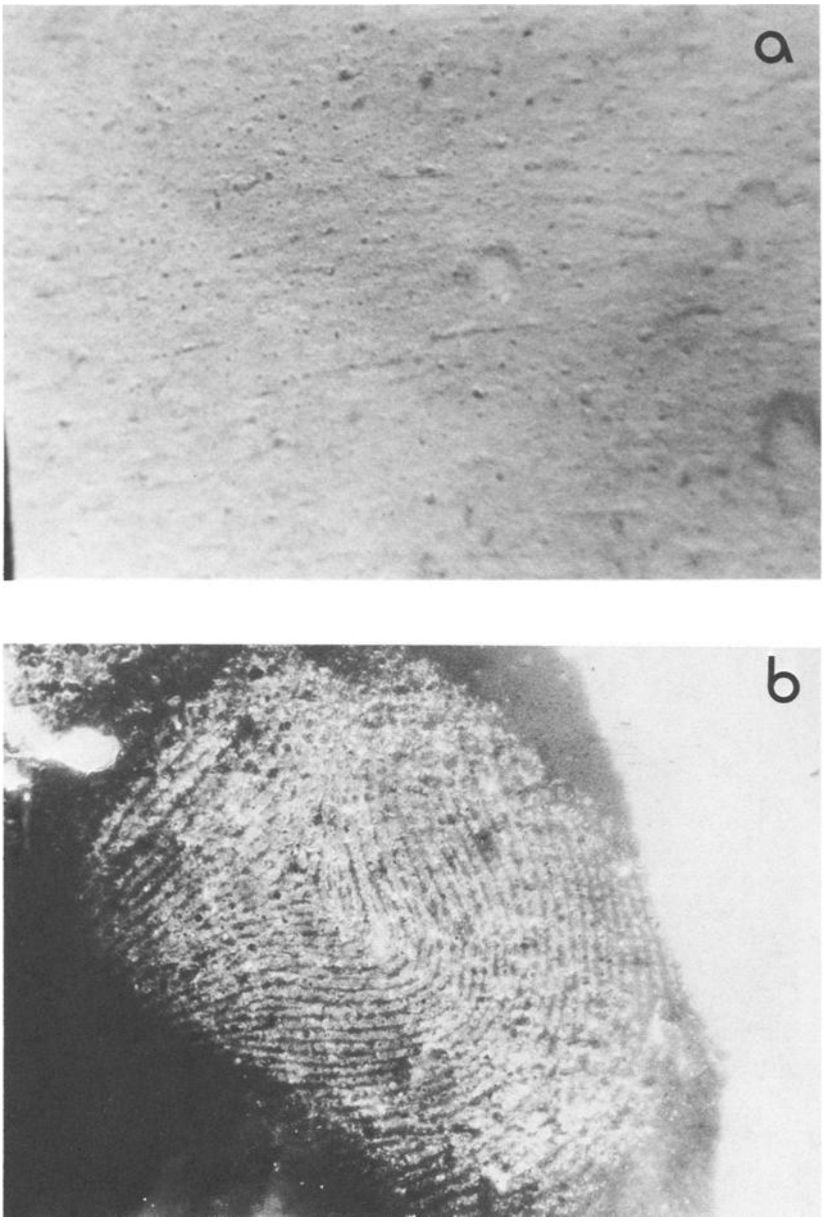

FIG. 13—*Fingerprint on sticky side of masking tape stained with a water solution of DODC as seen in room light* (a) *and under the Nd: YAG laser* (b).

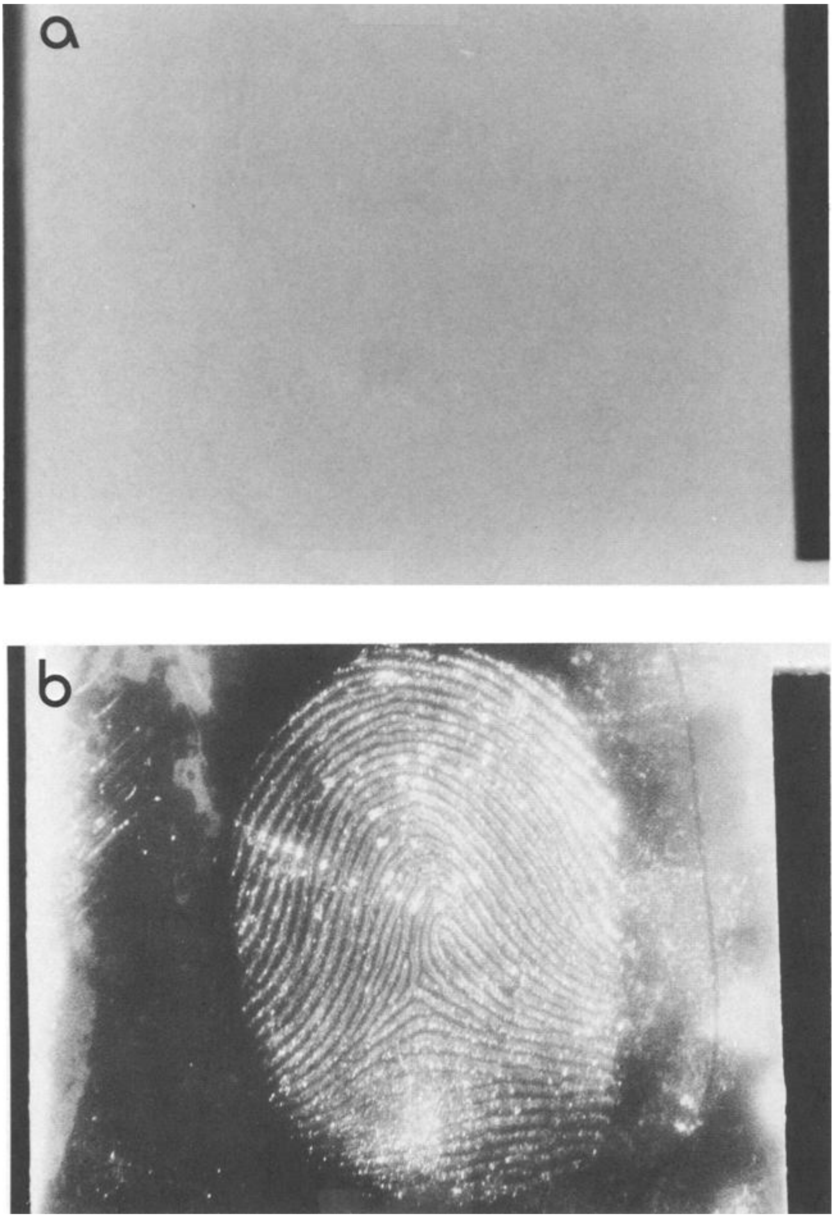

FIG. 14—*Fingerprint on plastic (light switch cover) fumed with cyanoacrylate ester and then stained with a methanol solution of DODC as seen in room light* (a) *and under the Nd: YAG laser* (b).

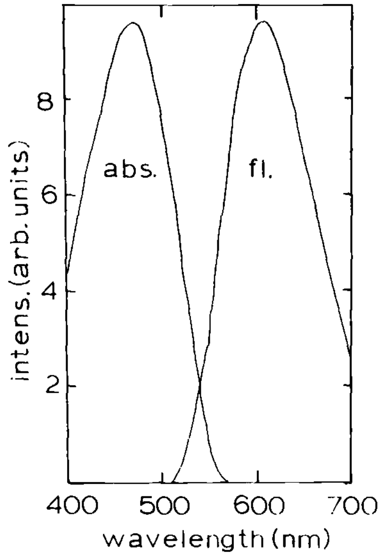

FIG. 15—*Absorption* (abs.) *and fluorescence* (fl.) *spectra of the laser dye DCM in methanol solution.*

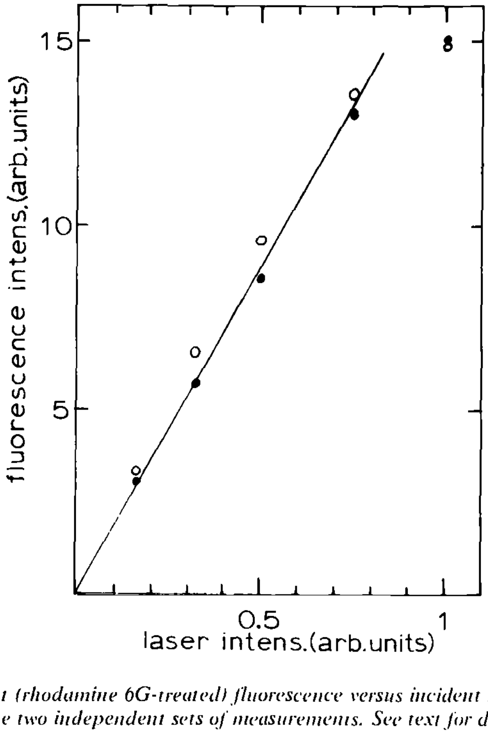

FIG. 16—*Fingerprint (rhodamine 6G-treated) fluorescence versus incident 532-nm laser light. Open and closed circles denote two independent sets of measurements. See text for discussion.*

strate the value of tailoring procedures to the laser one has on hand, in this instance the Nd:YAG laser.

The fact that fingerprints not visible to the eye can be developed by TV camera means that one can expect to see routine electronic, rather than photographic, fingerprint development in the near future. Electronic development also lends itself naturally to combination with computer image processing which is beginning to find application in the fingerprint field.

Acknowledgment

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References

[*1*] Dalrymple, B. E., Duff, J. M., and Menzel, E. R., "Inherent Fingerprint Luminescence-Detection by Laser," *Journal of Forensic Sciences*, Vol. 22, No. 1, Jan. 1977, pp. 106-115.

[*2*] Menzel, E. R., Burt, J. A., Sinor, T. W., Tubach-Ley, W. B., and Jordan, K. J., "Laser Detection of Latent Fingerprints: Treatment with Glue Containing Cyanoacrylate Ester," *Journal of Forensic Sciences*, Vol. 28, No. 2, April 1983, pp. 307-317.

[*3*] Herod, D. W. and Menzel, E. R., "Laser Detection of Latent Fingerprints: Ninhydrin Followed by Zinc Chloride," *Journal of Forensic Sciences*, Vol. 27, No. 3, July 1982, pp. 513-518.

[*4*] Menzel, E. R., "Laser Detection of Latent Fingerprints-Treatment with Phosphorescers," *Journal of Forensic Sciences*, Vol. 24, No. 3, July 1979, pp. 582-585.

[*5*] Menzel, E. R., "Laser Detection of Latent Fingerprints," *Law Enforcement Communications*, March/April 1983, pp. 4-5.

[*6*] Burt, J. A. and Menzel, E. R., "Laser Detection of Latent Fingerprints: Difficult Surfaces," *Journal of Forensic Sciences*, Vol. 30, No. 2, April 1985, pp. 364-370.

[*7*] Menzel, E. R. and Almog, J., "Latent Fingerprint Development by Frequency-Doubled Neodymium: Yttrium Aluminum Garnet (Nd:YAG) Laser: Benzo(*f*)ninhydrin," *Journal of Forensic Sciences*, Vol. 30, No. 2, April 1985, pp. 371-382.

[*8*] Menzel, E. R., "A Guide to Laser Latent Fingerprint Development Procedures," *Identification News*, Vol. XXXIII, No. 9, Sept. 1983, pp. 7-13.

[*9*] Menzel, E. R., *Fingerprint Development with Lasers*, Marcel Dekker, Inc., New York, 1980, Chap. 2.

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