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A Computer Interfaced Time-Resolved Luminescence Imaging System

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ABSTRACT: Time-resolved luminescence imaging using a computer-interfaced gateable digital camera is shown to be useful for laser fingerprint development on strongly luminescent substrates. The system design is optimized for rare earth fingerprint treatment chemistry. System specifications are detailed and operation is discussed. Other potential applications include DNA typing and bioassay.

KEYWORDS: criminalistics, fingerprints, lasers, luminescence, time-resolved imaging, DNA, bioassay

For quite some time now the technique of latent fingerprint detection via inherent and enhanced luminescence has been used by the law enforcement community. Unfortunately, though, many surfaces are intractable to the standard illumination and filtering techniques due to their strong background luminescences. This is particularly true when the background luminescence is similar in color to the fingerprint luminescence so that suppression of the background via optical filters is ineffective.

However, as the background luminescences generally are short-lived (lifetimes on the order of nanoseconds), one can take advantage of differences in luminescence lifetimes by a suitable choice of the chemistry utilized on the latent fingerprint (in order to yield microsecond or millisecond luminescence lifetimes) and by time-resolved or gated imaging techniques.

The basic principle of time-resolved luminescence imaging is depicted in Fig. 1. The laser light is repetitively modulated (chopped on and off) at a suitable rate that allows the long-lived fingerprint luminescence of interest to be excited. Of course, the short-lived background luminescence is also excited. The luminescence intensity decay $I = I_0 e^{-t/\tau}$ after illumination cut-off is rapid for the short-lived (nanosecond τ) background and slower for the longer-lived (microsecond to millisecond τ) fingerprint luminescence.

By gating the imaging device sufficiently far into the dark (laser off) period, the background luminescence will have decayed and only the fingerprint emission will be recorded. It is important to note that pulsed lasers are a poor choice as the excitation source because laser pulse widths are typically on the order of $t = 20$ nanoseconds, too short to effectively excite phosphorescence (long-lived luminescence). The laser pulse width should be comparable to the lifetime (τ), because the rise of the fingerprint lu-

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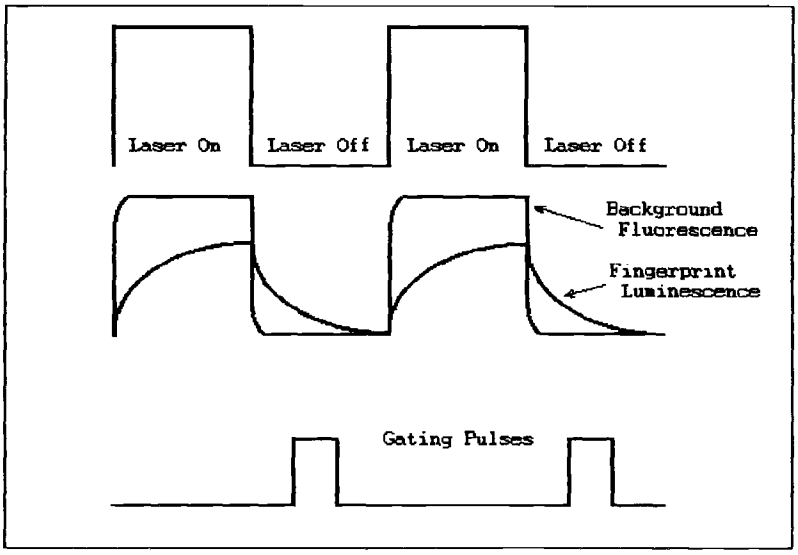

FIG. 1—*Principle of time-resolved imaging.*

minescence intensity after onset of the laser pulse follows the equation $I = I_0(1-e^{-t/\tau})$, or else the laser pulse intensity would need to be quite high, which would damage the article since highly fluorescent (short-lived luminescence) substrates absorb strongly.

The earliest attempt [*1*] to perform time-resolved luminescence imaging of fingerprints used a cylindrical light chopper that enclosed the article being examined (Fig. 2). The cylindrical chopper provided both the modulation of the excitation source as well as the gate width and delay. It imposed limitations on the size of the articles that could be examined and chopping speeds were low due to the mass of the cylinder.

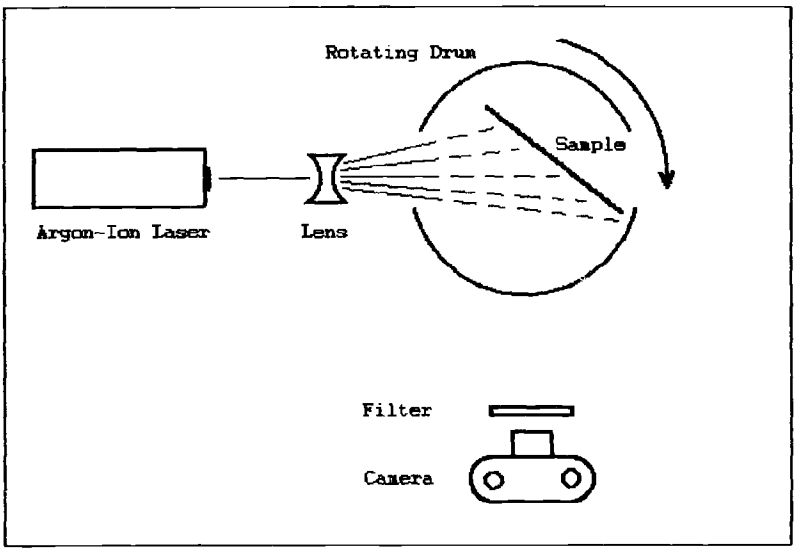

FIG. 2—*Cylindrical system, block diagram.*

Next came a 1st-generation time-resolved imaging system [2] (Fig. 3) which consisted of a gated microchannel-plate image intensifier mounted to a camera body (for ease of focusing) and utilized either a mechanical or an electro-optical modulator to chop the excitation source. The fingerprints were stained with ruthenium and copper complexes [3] (microsecond τ) or treated by ninhydrin and rare earth salts [4] (millisecond τ). The resulting complexes yielded enhanced rare earth luminescence via intramolecular energy transfer from Ruhemann's Purple to the rare earth ion.

Using the microsecond lifetime chemicals required the use of expensive electro-optical (E-O) modulators. More importantly, though, these E-O modulators require careful optical alignment and biasing in order to achieve adequate extinction of the laser intensity during the dark (laser off) period. When using the long-lived rare earth compounds, a mechanical light chopper (a rotating wheel with holes in it) is sufficient.

While this 1st-generation device was successful in its ability to perform fingerprint imaging with background suppression, cumbersome instrumentation made it suitable only for research and not for practical application. We have designed and constructed a more flexible second-generation prototype that satisfies the practicality requirements for use by the law enforcement community.

The Second-Generation System

A choice was made to match the system design to rare earth compounds with which fingerprints are treated either in a manner analogous to the now routine ninhydrine/zinc chloride treatment (for porous surfaces) or rhodamine-6G staining (for smooth surfaces). These rare earth compounds not only offer the prospect of a single chemistry useful for both porous and smooth surfaces [5], but also allow the utilization of a cheap and easy to use mechanical light chopper.

Our second-generation time-resolved luminescence imaging system (Fig. 4) uses a desk top computer and a digital CCD-camera incorporating a gateable microchannel-plate image intensifier, providing flexibility of image acquisition and processing, hard-copy output and the "user-friendly" operation required of a viable investigative tool.

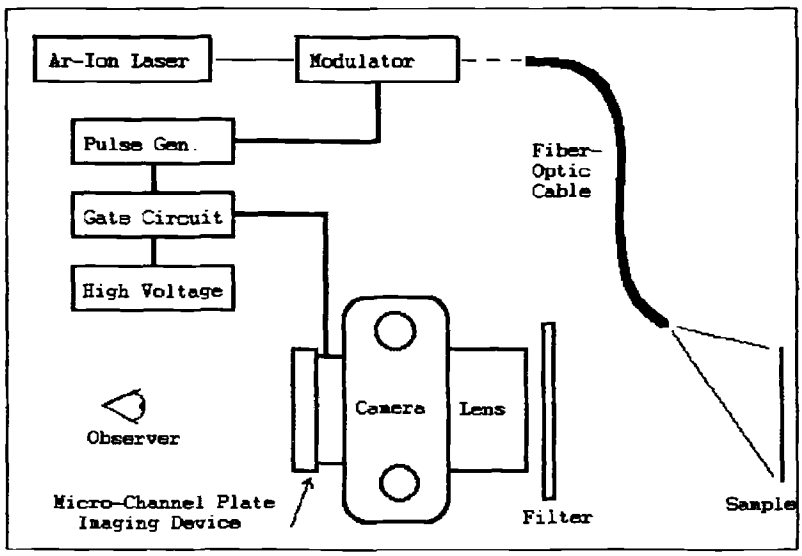

FIG. 3—*First generation system, block diagram.*

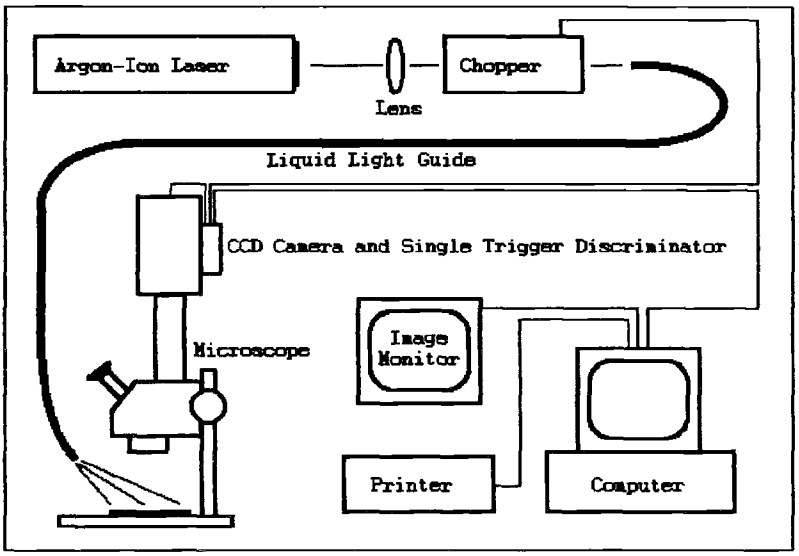

FIG. 4—*Second generation system, block diagram.*

The argon-ion laser (Coherent Innova 90-6 or Spectra Physics 171 in our system) is chosen as the excitation source for a number of reasons. As mentioned previously, pulsed lasers such as the nitrogen, frequency-doubled Nd:YAG and copper vapor lasers have pulses that are far too short to effectively excite the phosphorescent rare earth (Eu^{3+}, Tb^{3+}) compounds. The repetition rate of the pulsed Nd:YAG lasers is also too low, typically 12 to 20 Hertz in the units utilized by some law enforcement agencies. The argon-ion laser, however, produces a continuous output which can be chopped at any desired frequency, hence specific pulse width. Argon-Ion lasers are capable of producing blue, green and near-ultraviolet (UV) light and can also pump dye lasers, thereby making available excitation from yellow through red as well.

The laser output is tightly focused onto the chopper blade in order to obtain a sharp cut-off. Since the emissive lifetimes of Eu^{3+} and Tb^{3+} are 0.4 milliseconds and 1.3 milliseconds, respectively, a chopper frequency of 650 Hertz (both the laser on time and the laser off time are 0.77 ms), which is compatible with these rare earth luminescence lifetimes, was selected.

The chopped laser light is then transmitted to the article to be examined via a liquid light guide. This, rather than a fiber optic cable, was chosen because of its large diameter, which makes it unnecessary to refocus the divergent laser beam that exits from the light chopper. The liquid light guide transmits both visible and near-UV light.

The CCD camera (Stanford Computer Optics SIC 05 in our system), incorporates a gateable proximity-focused microchannel-plate (MCP) image intensifier driven by an internal microcomputer for digital image acquisition. The camera is activated by a single trigger discriminator in line with the mechanical chopper trigger output in order to open and close the shutter, i.e. gate the microchannel-plate imaging device. The specially modified single trigger discriminator (STD) of our system allows gating to a maximum of eight pulses per video frame. The STD module controls the CCD array exposure (eliminating multiple exposures during frame transfer) during the repetitive external trigger signal from the chopper so as to ensure proper synchronization of the video timing sequence during the 15.5 ms frame integration time. This 15.5 ms frame integration time is the maximum allowable time that the camera can be active during the 16.6 ms (60 Hz)

duty cycle. The choice of 650 Hz chopping frequency, together with imaging integration over eight laser pulses, is ideal in that it (almost) fully makes use of the available 15.5 ms video frame. Refer to Fig. 5 for a timing diagram.

The camera may be mounted either on a zoom-stereo microscope (an Olympus SZ40 in our system) or on a standard tripod. When mounted on the zoom-stereo microscope, a wide range of magnification is available for varied requirements. At low magnification an entire print is imaged (Fig. 6) while at higher magnification a small section of the print (Fig. 7) is shown in greater detail, potentially making use of pore structure for identification purposes. If the article being examined is oddly shaped or too large to fit under the microscope, the camera is mounted on the tripod and used with a standard photographic camera close-up lens. With our close-up lens, good magnification and a working distance on the order of 20 cm between the lens and the article under examination, that is, reasonably good depth of field, is obtained.

Camera controls consist of gate width, delay and maximum gain, and are set via the computer. Once these parameters are set, the gain is manually adjusted by a potentiometer on the camera in real time to protect the MCP from overexposure.

The interface consists of a 33 MHz Intel 80386 microprocessor based Gateway computer, two high-resolution monitors (one to manipulate the computer and the other to display the fingerprint image) and additional image processing hardware and software. The images are captured from the camera and stored to disk by a Data Translation DT2851 high-resolution frame grabber. The DT2851 converts the video signal at 10 MHz into 480 lines by 512 pixels per line by 8 bits per pixel (for 245.8×10^3 pixels per image, at 256 grey scales). ImagePro software provides some rudimentary image processing abilities such as contrast adjustment, edge enhancement and spectral (fast Fourier transforms) editing. An in-depth discussion of image processing is beyond the scope of this article. This topic is taken up in a separate article [*6*]. Nonetheless, a short discussion of FFT editing is appropriate.

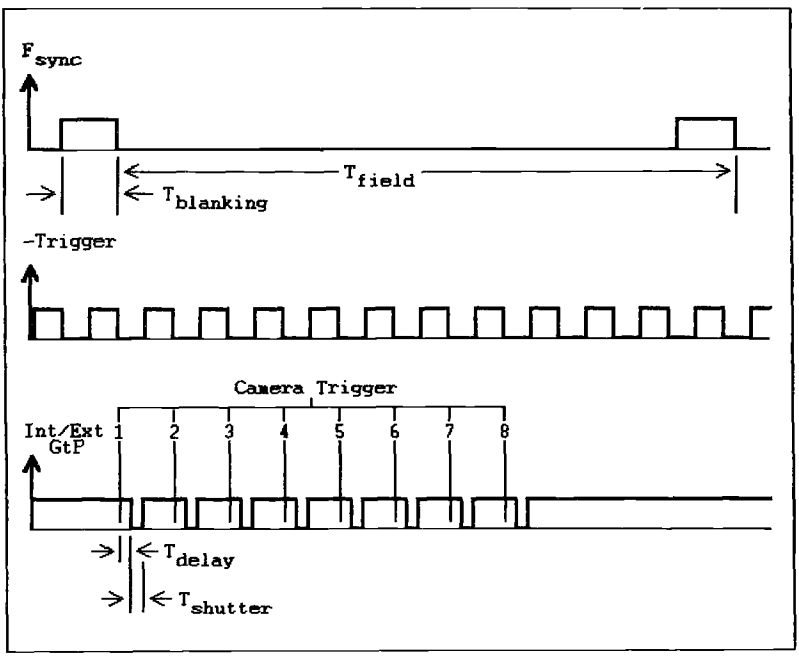

FIG. 5—*Camera timing diagram.*

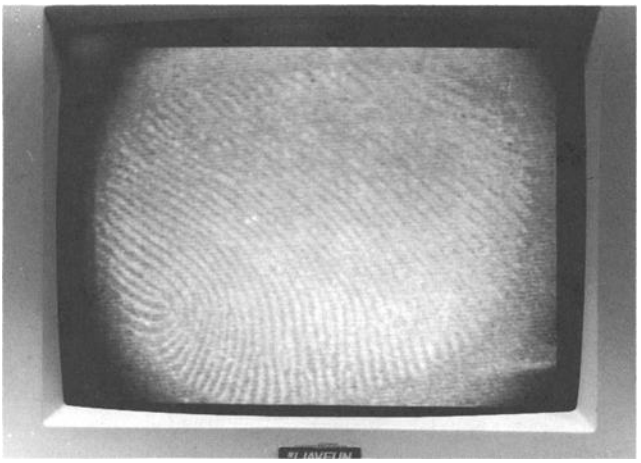

FIG. 6—*Entire print (on monitor).*

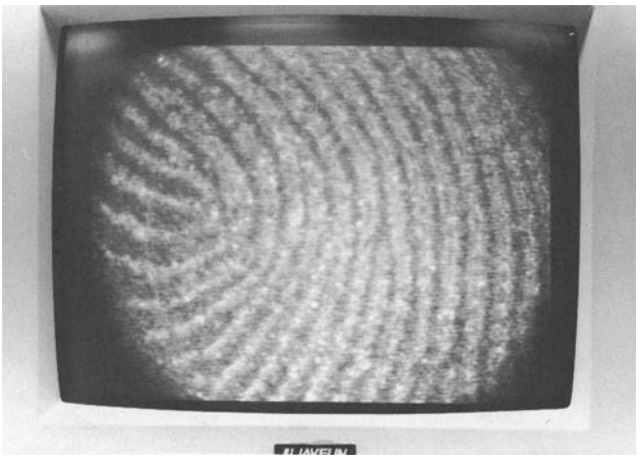

FIG. 7—*Magnified section of print (on monitor).*

With the various rare earth treatments, particularly on porous surfaces, there is a tendency for formation of a uniform background due to the deposition of unreacted rare earth salts everywhere on the treated surface. This can be easily eliminated by taking the Fourier transform of the image and then editing (removing) the central spot (DC component of the spectrum) from the field. The inverse transform of the edited field yields the original image minus the uniform background (Fig. 8).

Various forms of output are available. Hard copy can be produced by the many types of printers available: dot matrix, laser and thermal. Of the three types tested, the thermal printer seems to have the optimum combination of resolution and grey scale reproduction for fingerprint images. Additionally, the digitally stored images can potentially be transferred directly to the Automated Fingerprint Identification System (AFIS) now gaining use in the law enforcement community.

The system is, of course, useful for fingerprint work when background fluorescence is not a problem. One then simply shuts the light chopper off (giving continuous laser

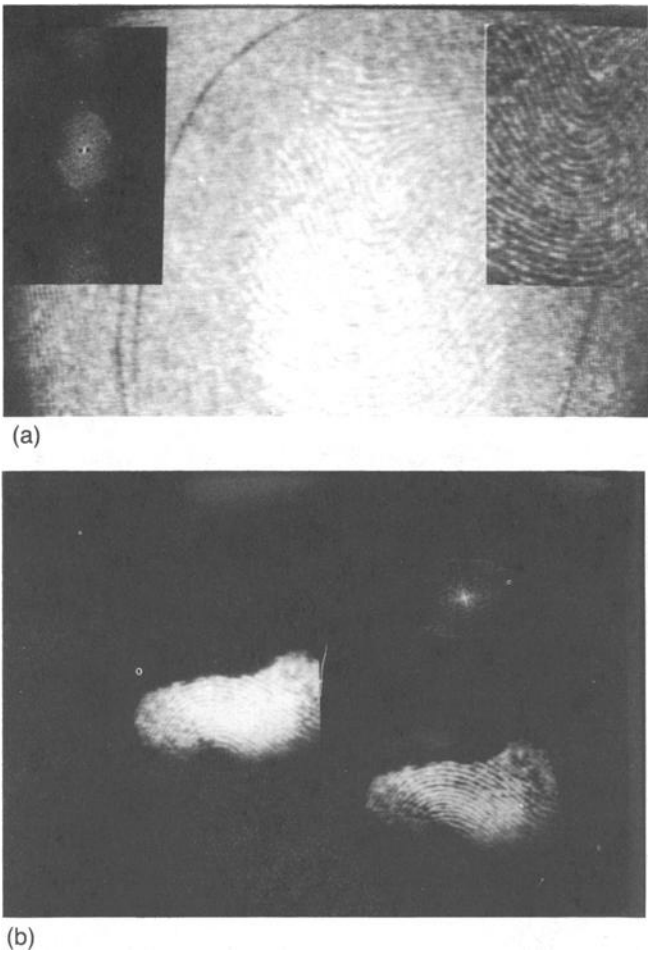

FIG. 8—*Examples of fingerprint image enhancement.* (a) *Edited FFT* (left), *original image* (center), *processed image* (right); (b) *original image* (left), *edited FFT* (upper right), *processed image* (lower right).

illumination of the article under scrutiny) and operates the digital camera in the ungated mode. The system is depicted in Fig. 9.

An example of the ability to suppress background luminescence is depicted in Figs. 10 and 11. A ruby crystal simulates the phosphorescent signal of interest (τ = 4.3 ms for ruby) and a vial of rhodamine-6G (Rh-6G) solution simulates the fluorescent background. The samples were illuminated by green laser light from the argon-ion laser. Figure 10 shows the ungated image and Figure 11 shows the gated image with the Rh-6G fluorescence suppressed. *Ref 5* shows the analogous situation for an actual fingerprint.

In presenting the images obtained with our system, we have chosen to photograph the monitor screen (rather than printing the image files) for presentation of Figs. 6 to 8 because we expected that too much detail would be lost in reproduction in print of images from the thermal printer. Figures 10-11 are thermal printer output (here the contrast and resolution were not an issue).

Other possible uses of the time-resolved imaging system extend to DNA typing and labeling, immunoassays and bioassays in conjunction with rare earth labeling compounds

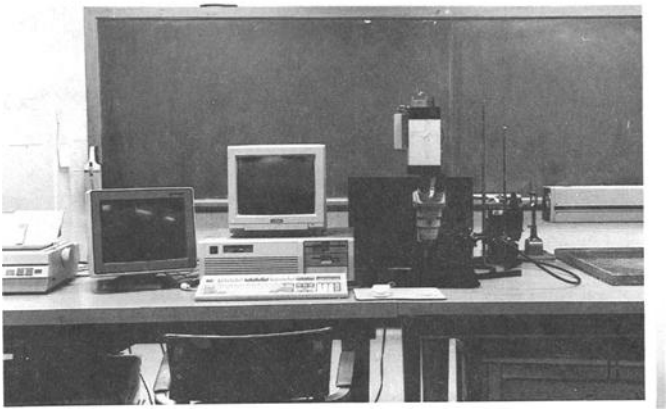

FIG. 9—*Second generation TRI system.*

[*7–13*]. Rare earth labels for a variety of biological purposes are commercially available (for example, from Pharmacia Wallac and Kronem Systems). We believe that much speed and sensitivity might be gained in forensic DNA profiling if radiolabels (^{32}P) were to be replaced by rare earth labels. Our reasoning is that a radioactive element produces one event only whereas a rare earth ion will yield many (luminescence) photons during the excitation time (which spans some six ms per image with our system). Sensitivity is provided also by the high powers (several Watts, up to about seven) in the near-UV (as appropriate for excitation of the rare earth luminescences) of modern argon-ion lasers and by the digital cameras, which, after all, are designed for very low light level imaging. Finally, the long X-ray film development involved in radiolabeling is bypassed and entry of the image to the computer for analysis is direct.

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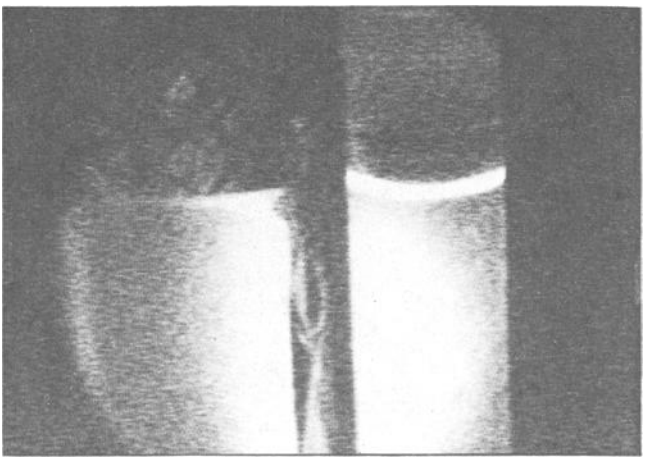

FIG. 10—*Ruby crystal/Rh-6G solution, ungated image.*

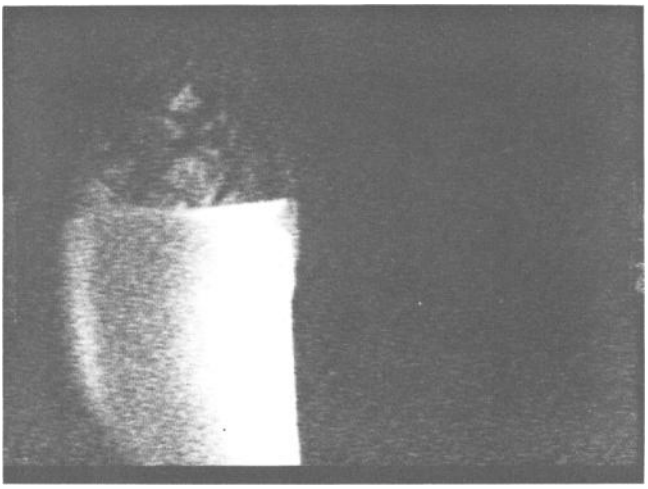

FIG. 11—*Ruby crystal/Rh-6G solution, gated image.*

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