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# Laser Excited Luminescence of Inclusions and Fibers in Paper Matches

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**ABSTRACT:** Luminescing inclusions and fibers were located in paper matches by means of two lasers. The size, color, and intensity of luminescence varied from match to match. Paper matches could quickly be compared to each other. Forty-one match books were collected. They were illuminated with a 5-W argon laser operated in the broad band mode or a dye laser set at 593 nm. All matches were examined visually with optical equipment and some with infrared film. The argon laser revealed more luminescing inclusions, whereas the dye laser excited more fibers. Since only a small number of inclusions and fibers luminesced, they stood out from the mass of fibers constituting paper matches.

**KEYWORDS:** forensic sciences, matches, luminescence

The comparison of paper matches has been practiced in forensic science for many years. In 1968, Funk [*1*] discussed the examination of inclusions, protrusions, and fibers using a stereo microscope and tungsten light. Dixon [*2*] enlarged on the examination by stressing fibers and suggesting two criteria: (1) four or more prominent fibers in addition to corresponding class features for a positive identification, or (2) one pair or more of matching inclusions together with a torn end and corresponding class features.

The comparison of paper matches, however, remains tedious and time-consuming. Small or indistinct inclusions are not easily located and the alignment of surface fibers on two matches remains difficult. This paper explores the use of an argon laser and a dye laser to find and match luminescing inclusions or fibers.

## Materials and Methods

Forty-one match books were collected between 1980 and 1984. Twenty-one of these were made in the United States, the rest in Canada. The U.S. books were produced by eight companies with plants situated in seventeen different locations. The Canadian books were made by six companies with plants situated in nine different locations. A match book usually consists of two rows of match boards stapled to a cover. To form the individual matches, the match boards are cut into ten or more sections by the manufacturer. The top surface of the matches is usually coated with white or off-white paper, but some matches are stained with colored dyes. The underside shows the natural brown or gray color of the board.

The two rows of match boards were removed from all folders, and the examination was approached from two directions:

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(1) Both surfaces of the boards were searched for luminescing inclusions and fibers with a 10-cm reading glass;

(2) The cut sides of 120 individual paper matches removed from 6 books were searched for inclusions with a stereo microscope set at ×15. Both lasers were used to provide illumination for both approaches.

The lasers were manufactured by Coherent. The argon laser, model Innova 90-5, was used in the broad band mode that embraces the range 457 to 514 nm. The 1.5-mm beam was enlarged with an ALM beam expander, model LFT-20, and then reflected onto the matches with a first surface mirror. A 201-mm plano convex lens was also used to size the beam when a smaller and more intense beam was required. The yellow barrier filters were Fisher 11-409-50A or Schott KV550 [3]. The KV550 has a lower inherent fluorescence and therefore produces greater color contrast.

The dye laser, model CR-599, was excited by the above argon laser. The dye laser was filled with Rhodamine 6G dye, and the birefringent filter was set at 593 nm for maximum output. The red barrier filter was a Wratten No. 92, which transmits from 620 nm into the infrared.

All photography was done with a 4 × 5 view camera and one of two macro lenses, 100 mm or 65 mm. The film was Plus-x or, when extra contrast was required, Tech Pan. Exposure times were originally arrived at by trial and error and later based on successful photographs. They ranged from 10 s for the argon laser to 5 min for the dye laser, and varied with magnification, beam size, and intensity of exciting light and intensity of emitted luminescence. The shortest exposures were limited by the heat that the subject could tolerate before the beam caused it to warp, emit vapors, or char.

Examinations in the infrared were also made of the underside of 28 books. The exciter source was the argon laser, and the luminescence was recorded on Kodak High Speed Infrared Film through a Wratten 89B filter.

The ultraviolet fluorescence photograph was made with two Hanovia lamps, type 7420, equipped with 6527-B filters, which transmit short and long ultraviolet radiation. The film was Tri-X, and the barrier filter was a Wratten No. 3.

## Results and Discussion

### *Inclusions Observed with the Argon Laser*

Fifteen books had two or more luminescing inclusions on the grey underside when searched with a reading glass (Fig. 1). Only one book had inclusions on the white top side.

Fifty-nine paper matches out of a total of one hundred and twenty had two or more luminescing inclusions on one cut side. These inclusions corresponded with inclusions on the adjacent match. The largest number of corresponding inclusions that luminesced was five pairs.

Figures 2 through 5 show the cut sides of two matches illuminated with tungsten light and with the argon laser. No great variation was noted in the color of the luminescing inclusions. Most were yellow, but occasionally there were red or green ones.

### *Inclusions Observed with the Dye Laser*

Seventeen books had two or more luminescing inclusions on the gray underside when searched with a reading glass. Only one book had luminescing inclusions on the white top side.

The same 120 matches that were examined with the argon laser were also examined with the dye laser. Thirty-five had two or more luminescing inclusions that corresponded with inclusions on the adjacent match. Some of these inclusions were visible only with the dye

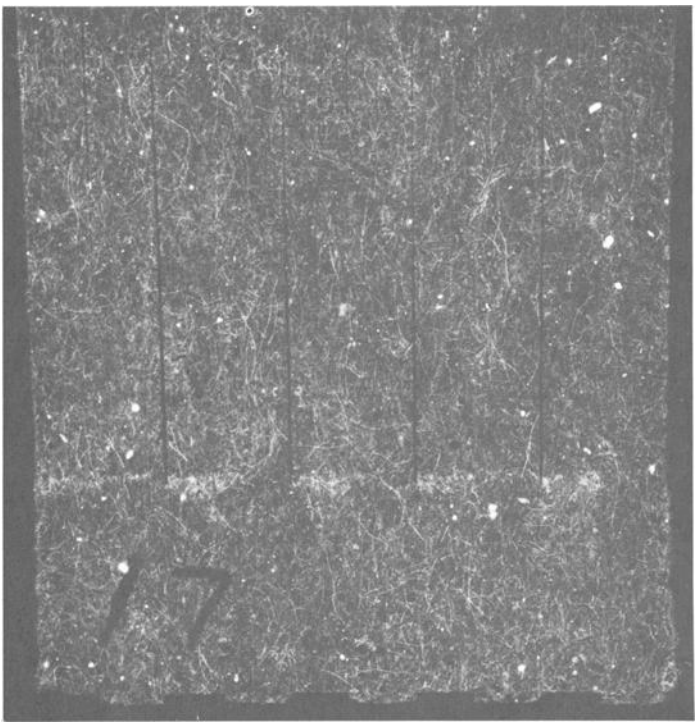

FIG. 1—*Luminescing inclusions revealed with an argon laser (×3.4).*

laser (Figs. 6 and 7). Others could also be seen with the argon laser. The colors of the inclusions were various shades of red. The maximum number of luminescing and matching inclusions found on any two matches was seven pairs.

### *Surface Fibers Observed with the Argon Laser*

Luminescing fibers in significant numbers were not found on either side of the matches when searched with a reading glass. The exceptions were four books that had been stained black. On those a large number of fibers luminesced in various shades of yellow, red, and brown, and a few luminesced in green.

The infrared luminescence photographs of the underside of 28 match books revealed that 15 books had luminescing fibers in substantial quantities (Fig. 8). (Figure 8 shows the same book shown in Fig. 1). For purposes of comparison the book was also photographed by ultraviolet fluorescence (Fig. 9). The two techniques complement each other.

The search for luminescing fibers in the infrared, however, should not be the first choice because they cannot be seen with the unaided eye. The matches must be photographed to discover the presence of fibers.

### *Surface Fibers with the Dye Laser*

Fourteen books had luminescing fibers on the top side but only nine books had luminescing fibers on the underside when searched with a reading glass (Table 1). The fibers were of an orange to red color and were readily seen and photographed. Figure 10 shows that the

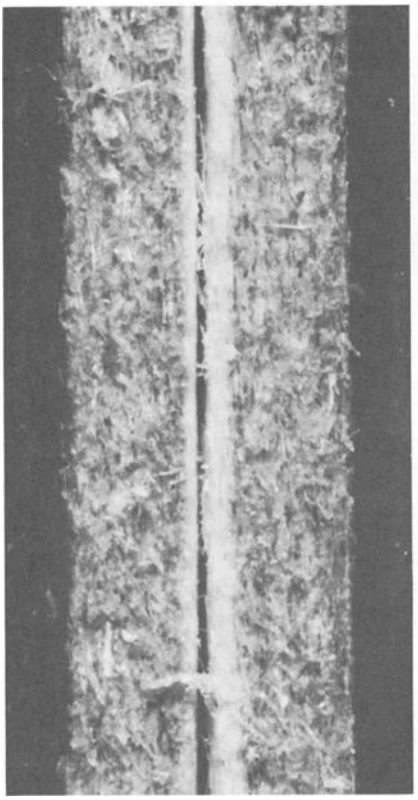

FIG. 2—*The sides of two adjacent matches seen with tungsten light (×25).*

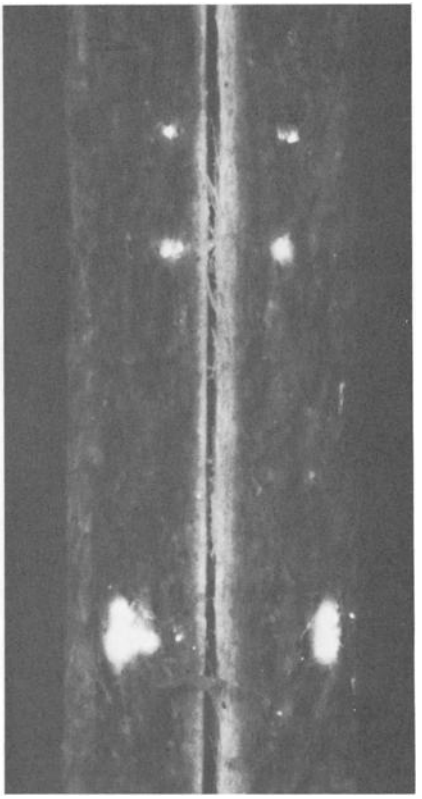

FIG. 3—*The argon laser revealed three corresponding pairs of inclusion on the same two matches as in Fig. 2 (×25).*

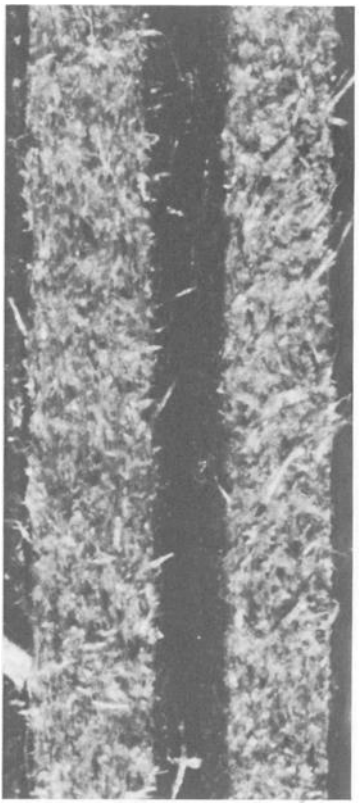

FIG. 4—*The sides of two paper matches seen with tungsten light (×25).*

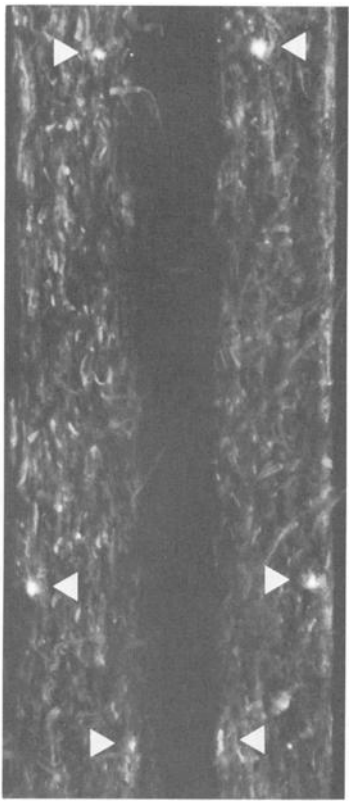

FIG. 5—*Luminescing inclusions were found in many sizes. These two matches have three matching pairs (×25).*

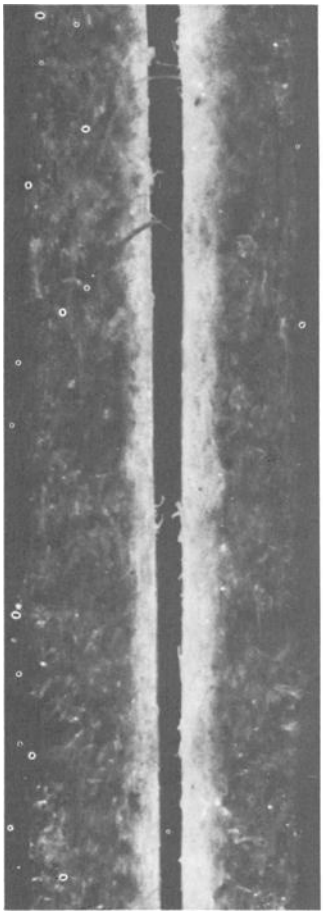

FIG. 6—*Two adjacent matches observed with the argon laser (×20).*

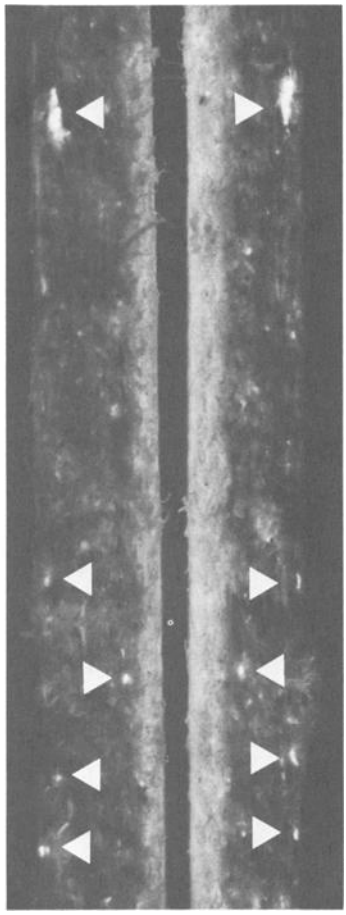

FIG. 7—*The dye laser revealed five pairs of inclusions that were not visible with the argon laser (×20).*

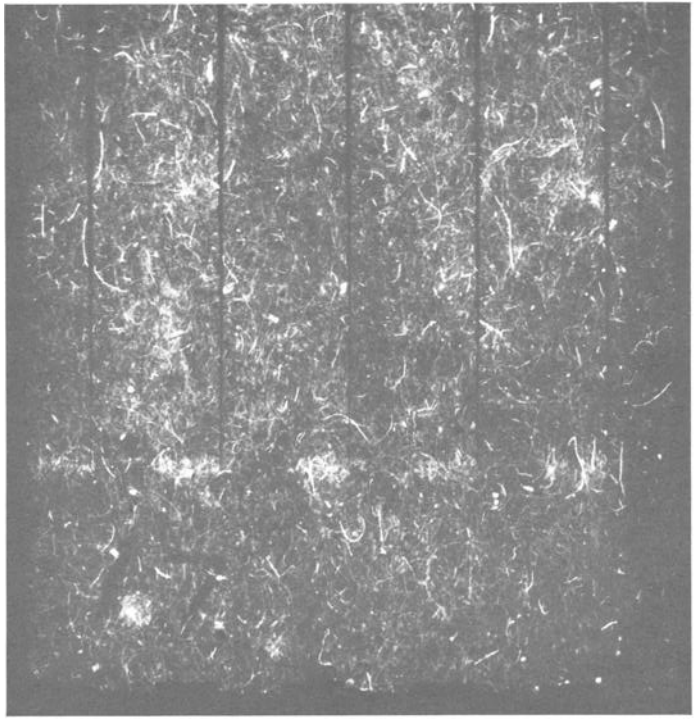

FIG. 8—*Luminescing fibers revealed with an argon laser, infrared film, and filter (×3.4).*

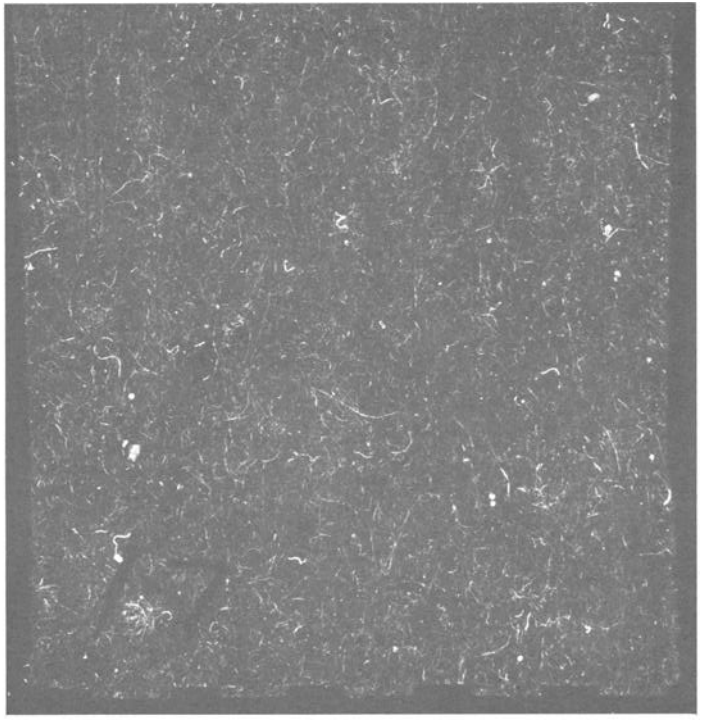

FIG. 9—*Ultraviolet fluorescence of the same matches shown in Figs. 1 and 8 (×3.4).*

TABLE 1—*Results of analysis of 41 match books.*

| | Argon Laser | Dye Laser |
|---|---|---|
| Inclusions | 15 | 17 |
| Fibers | 4[a] | 9 |

[a]Stained books.

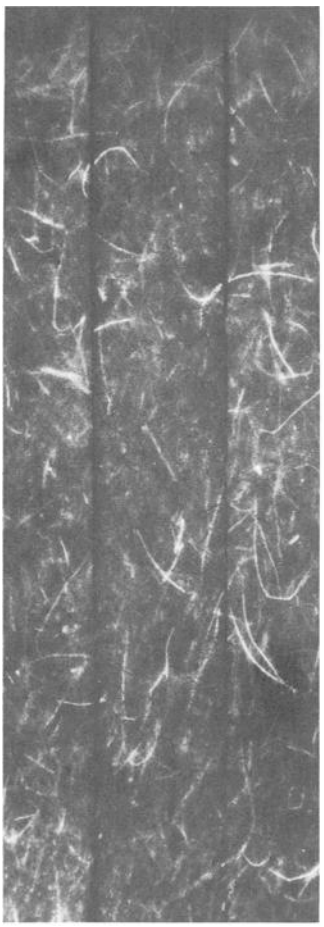

FIG. 10—*The paper match in the center shares at least nine fibers with its two neighbors; photographed with a dye laser (×8).*

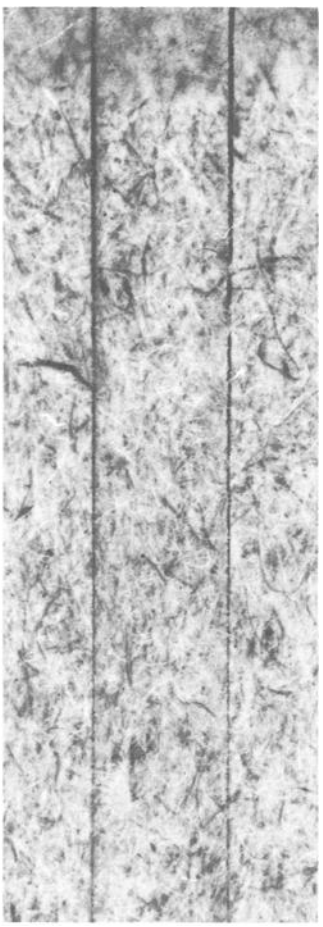

FIG. 11—*Ultraviolet fluorescence photograph of the same three paper matches as shown in Fig. 10 (×8).*

center match shares luminescing fibers with its two neighbors. Figure 11 is of the same three matches by ultraviolet fluorescence.

## Conclusion

Two lasers were used to excite inclusions and fibers in paper matches. The argon laser produced more luminescing inclusions whereas the dye laser excited more fibers.

When searching for inclusions the argon laser should be the first choice. It will probably reveal more luminescing inclusions, and they will luminesce more strongly than with the dye laser. Inclusions of different colors were also found with the argon laser and therefore were easier to discriminate and photograph. The dye laser, however, can reveal some inclusions that are not excited by the argon laser, including the cross-sections of a single fiber.

The dye laser should be the choice of the three techniques discussed when searching for matching fibers. Since only a relatively small number luminesced, they stood out from the mass of fibers constituting a paper match.

Inclusions and fibers are more easily located with lasers than with tungsten light. The photography of luminescing inclusions is similar in complexity to photomacrography of matches with tungsten light.

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