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Laser Examination as an Additional Nondestructive Method of Ink Differentiation

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ABSTRACT: Twenty-two black, eight blue, and seven red inks were compared using the reflectance and luminescence mode of the Model J infrared instrument and the Laser Photonics, Inc., neodymium yttrium aluminum garnet (Nd:YAG) laser. These thirty-seven inks were compared from writing produced on Cascade Xerographic paper and Dixon Paper Company safety paper. Results indicate that, in addition to the Model J instrument and other traditional nondestructive examinations, Nd:YAG laser examination in several instances produces different results, adding another feasible link to nondestructive processes commonly used. Further, the outcome of the comparison process was affected significantly on some occasions by the type of paper on which the writing appeared.

KEYWORDS: questioned documents, lasers, inks

There are several nondestructive methods for differentiating between inks which do not require special instruments and include direct viewing of similar inks under a strong light source to compare variations in color in terms of intensity and purity. Examination by ultra violet light—both short and long wave—can be performed. Dichroic filters allow the transmittance of two wavelengths of light at the same time which transmit a large portion of the red region of the visible spectrum, and very little of the blue-green. A correlation has been noted between the use of such filters and the results obtained with infrared reflectance and luminescent photography [*1*].

There has been a great deal of research in the last few years on the usefulness of argon ion lasers for the excitation of luminescence in the infrared region of the spectrum related to document examination and, in particular, ink differentiation. The possible differentiation of inks exposed to laser illumination first was described by Menzel [*2*]. Successful results in using the argon ion laser technique for the excitation of infrared luminescence was reported later in case work by Dalrymple [*3*]. More detailed use of laser induced luminescence and spectroscopy for differentiating between inks, and procedures for the enhancement of luminescence has also been documented [*4*]. Tappolet [*5*] evaluated the complementary effects of using visible and infrared luminescence for ink discrimination. Other authors also have expanded research in document examination beyond ink differentiation to include alterations, erasures, and other applications [*6*]. Also included are additional forensic science applications such as the enhancement of shoe prints and physical matches [*7*].

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The Aurora Police Department (APD) Laboratory acquired a portable laser in 1984 to aid primarily in the search and development of potentially identifiable latent prints. This instrument is a solid-state frequency doubled neodymium yttrium aluminum garnet laser (Nd:YAG laser), operating at 532 nm. It is a pulsed laser of about 7 mJ, with pulse duration of about 10 ns. Pulse frequency is about 20 Hz. The average power is approximately 140 mW. The goggles used are orange long wavelength pass filters with a cutoff point of about 570 nm. Experimental work at the APD Laboratory and in the field with this unit using procedures and techniques developed for use with argon ion lasers met with mixed results. For instance, the inherent or native luminescence of fingerprints has thus far never been observed with this unit.

The approach to this paper is based on such experience. Although successful results were reported by others on ink differentiation and other forensic science applications for argon ion lasers, the authors were interested in discovering if similar results also might be obtained with the Nd:YAG laser.

This unit differs from argon ion lasers in several respects. First of all, there is a difference in power. Various models of argon ion lasers are capable of delivering an overall power of from 2 to 20 W. The Nd:YAG laser power is about 140 mW. To place this comparison in perspective, 0.14 W versus 2 to 20 W.

Secondly, the monochromatic emission of the Nd:YAG laser is at 532 nm. Argon ion lasers can be operated all lines blue green, or tuned by the rotating prism to operate at single lines (457.9, 465.8, 472.7, 476.5, 488.0, 496.5, 501.7, and 514.5). The strongest single lines are at 488 and 514.5 nm [*8*].

A compensating factor for the Nd:YAG laser power is that the wavelength, at 532 nm, appears as a very intense, bright green. In considering wavelength, as it relates to psychophysics, equal energy monochromatic stimula of a different wavelength results as sensations of different brightness. "Given a spectral green and a spectral blue of the same high radiance, the green appears brighter" [*9*, p. 25]. The photopic sensitivity curve of brightness peaks at about 555 nm, and this aspect undoubtedly adds to the perceived intensity of the Nd:YAG emission. Also, the pulsed light may compensate slightly for color fatigue of the eye ordinarily encountered by continuous illumination and by viewing of bright colors.

Given these considerations of differences between types of laser units, the experiment proceeded. Two types of paper were used to observe the differences in results obtained, if any, due to type of paper used and color background.

Method

Twenty-two black, eight blue, and seven red inks were compared using the infrared reflectance and luminescence mode and the Nd:YAG laser. The groups were divided into ballpoint inks and "other." These thirty-seven inks were compared from writing produced on Cascade Xerographic paper (white), and Dixon Paper Company Blue Basketweave LaMonte safety paper, commonly used for the printing of personal and business checks. Since human response to visual stimuli is highly subjective, examinations were performed independently by the authors, and each description of the visual impressions was in agreement.

The filters of the Model J unit in the reflectance mode pass all wavelengths longer than about 900 nm, and attenuate everything less. The range extends to about 1200 nm. To excite luminescence, the unit is accompanied by an intense light source of a narrow band which excludes all red and infrared light. The overall range attenuates wavelengths less than 650 nm and passes up to 1200 nm.

While the use of short- and long-wave ultraviolet light as a source of excitation was not of primary concern in this study, a cursory scan revealed some interesting results for "other" red inks. The light used was a model UVGL 54 Mineral Light, operating at 254 to 366 nm.

A Nikon FE 2 camera was used for photographing the infrared reflectance and luminescence, and the laser luminescence exposures were made on automatic time setting at F2.8, using Kodak Ektachrome 160 film. For photographing infrared luminescence through laser illumination, the goggles were used at the lens as a filter. Photographs of infrared reflectance and luminescence were made directly from an RCA TV Monitor hooked up to a CCD Video Camera Module, using an 18% copper sulfate filter.

The terms "fluorescence" and "luminescence" are used to describe perceived results. Fluorescence is the emission of electromagnetic radiation as a visible light only during the absorption of radiation from a particular source, that is, an ultraviolet light. Any continuation of visible radiation after the source has been removed is phosphorescence. Since there may be some phosphorescence occurring with infrared radiation, the term used to describe these effects is "luminescence."

Results

The results from the reflectance mode of the image converter on both types of paper were consistent throughout. Differences were found in infrared luminescence produced by the Model J instrument and the laser; also, paper affected outcome.

Red Inks

In Table 1 are listed the results of the ultraviolet illumination and resulting fluorescence with "other" red inks only. No differences were observed between short- and long-wave luminescence. Ultraviolet fluorescence was noted on Sample 2 on both papers and on the Cascade paper, distinguishing this ink from all others. Further, Samples 1 and 7 fluoresced on the Dixon paper only, showing the effects of background on fluorescing properties.

The results of the infrared unit and laser responses for red inks are listed in Table 2. The type of paper clearly affected the observed outcome in comparing both Model J (Figs. 1*a* and *b*) and laser luminescence, as shown in Fig. 2.

Blue Inks

No ultraviolet fluorescence was noted for any of the blue or black inks. The response of Model J and laser techniques for blue inks is shown in Table 3. Samples 4, 5, and 8 inks appeared black when viewed with the laser. Paper color was not a factor for blue inks, except that the ink luminescence appeared brighter on the Cascade paper than on the Dixon paper.

TABLE 1—*Results of ultraviolet illumination and resulting fluorescence with red inks.*[a]

Pen Sample Number and Description	Cascade Paper	Dixon Paper
1. Pilot Razor Pt.	NF	F
2. SC-UF Pilot Perm.	F	F
3. Flair Felt Tip	NF	NF
4. Sharpie Felt Tip	NF	NF
7. R100 Rolling Writer Pentel	NF	F

[a]Key for tables: F = fluorescence, NF = no fluorescence, I = dark image, NI = no image, L = luminescence, L* = faint luminescence, and NL = no luminescence.

TABLE 2—*Results of infrared unit and laser responses for red inks.*[a]

Pen Sample Number and Description	Cascade Paper			Dixon Paper		
	Model J		Nd:YAG	Model J		Nd:YAG
	Refraction	Luminescence	Luminescence	Refraction	Luminescence	Luminescence
Ballpoint:						
5. PM Bic Deluxe MP	NI	L	L	NI	NL	NL
6. PF Bic Auditor's Fine Point	NI	L*	L*	NI	NL	NL
Other:						
1. Pilot Razor Pt.	NI	L	L	NI	NI	L
2. SCUF Pilot Perm.	NI	L	L	NI	L	L
3. Flair Felt Tip	NI	L*	NL	NI	NL	NL
4. Sharpie Felt Tip	NI	L*	L*	NI	NL	NL
7. R100 Rolling Writer Pentel	NI	L*	L	NI	L*	L

[a]See Table 1 footnote for explanation of abbreviations.

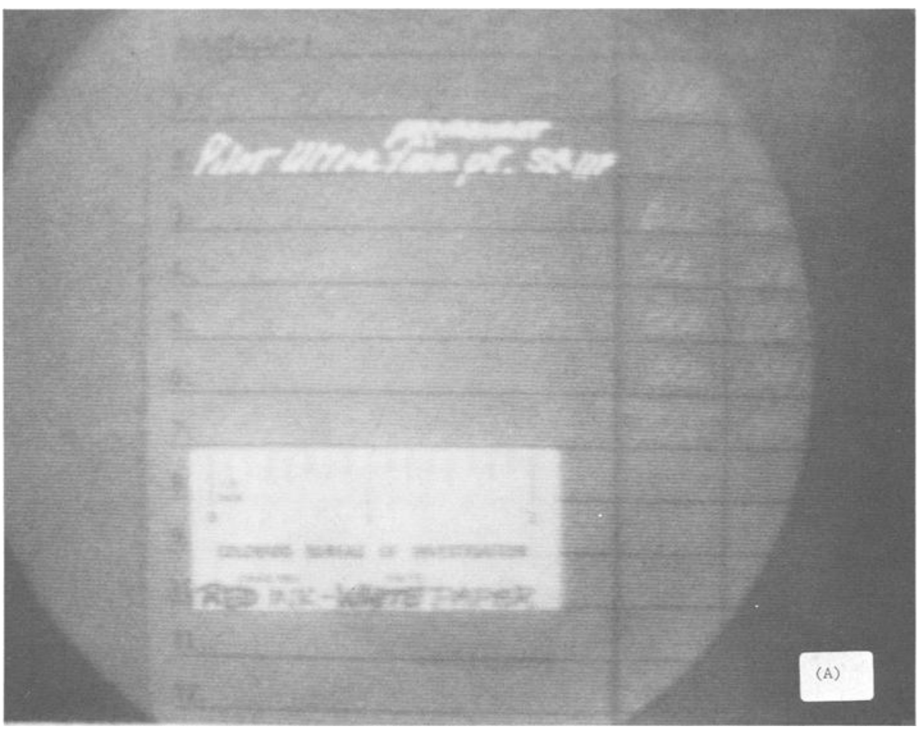

FIG. 1*a*—*Red ink. Faint luminescence noted by authors at time of examination of red inks did not show up clearly on infrared photographs on either the Cascade paper or the Dixon paper.*

FIG. 1b—Red ink. Pen samples Nos. 3 and 4 did not appear as an image when viewed directly through the Model J. Nevertheless, when photographed directly from the RCA TV monitor, the images are clearly visible.

Black Inks

The observed results for black inks are listed in Table 4. No additional distinctions were made by use of the laser, except for Inks 20 and 21 which appeared, under laser illumination, as green. All other inks remained black. This particular phenomenon is fugitive over time. From the time the authors originally observed this bright green color to the time of photographing results, the inks no longer appeared green. A portion of the sample of black inks, to include Samples 20 and 21, were redone with fresh inks to capture the original findings. This green differentiated the R100 Rolling Writer Pentel and the Superball Pentel inks from all other black inks. This laser luminescence is shown in Fig. 3. The lack of luminescence for other black inks is probably because such inks absorb in this region of the electromagnetic spectrum. This is also probably true for many blue inks.

Effects of paper background were significant for the Model J luminescing properties of the Pilot Razor Point and the Pilot Fineliner pens in that no image at all was observed on the Dixon Paper.

Discussion

The basic questions of the research were answered. The Nd:YAG laser does have a value as a further nondestructive screening device for inks in addition to the Model J reflectance

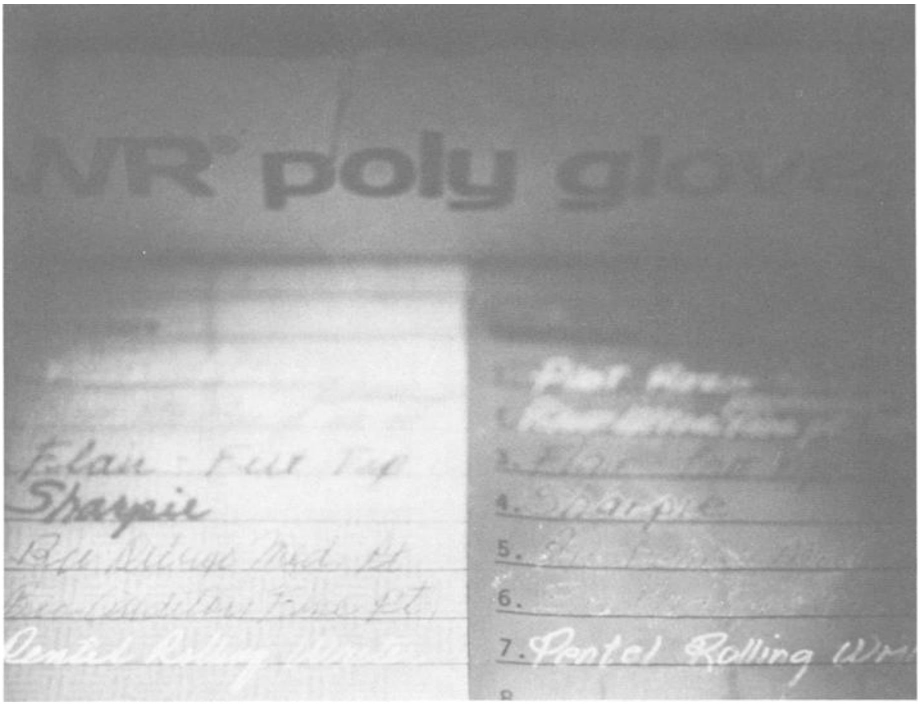

FIG. 2—*Laser luminescence of red inks.*

TABLE 3—*Response for blue inks.*[a]

Pen Sample Number and Description	Cascade Paper: Model J Refraction	Cascade Paper: Model J Luminescence	Cascade Paper: Nd:YAG Luminescence	Dixon Paper: Model J Refraction	Dixon Paper: Model J Luminescence	Dixon Paper: Nd:YAG Luminescence
Ballpoint:						
4. Bic	NI	NL	black	NI	NL	black
6. Faber Castell Sp. Med. 7623 Blue	I	NL	NL	I	NL	NL
7. Cross 2K GF	NI	NL	NL	NI	NL	NL
Other:						
1. Pilot	NI	L	NL	NI	L*	NL
2. Eraser Mate 2	NI	NL	NL	NI	NL	NL
3. Scripto Erasable Med. Blue	NI	NL	NL	NI	NL	NL
5. Scripto Easy Roller	NI	L	black	NI	L*	black
8. Pentel Super Ball	NI	L	black	NI	L*	black

[a]See Table 1 footnote for explanation of abbreviations.

TABLE 4—*Results for black inks.*[a]

Pen Sample Number and Description	Cascade Paper: Model J Refraction	Cascade Paper: Model J Luminescence	Cascade Paper: Nd:YAG Luminescence	Dixon Paper: Model J Refraction	Dixon Paper: Model J Luminescence	Dixon Paper: Nd:YAG Luminescence
Ballpoint:						
3. Pilot BP-S Med.	I	NL	NL	I	NL	NL
5. Bic Auditor's Fine Pt.	NI	L	NL	NI	L	NL
6. Bic Biro Med. Pt.	NI	L	NL	NI	L	NL
7. PM Bic Deluxe Med. Pt.	NI	L	NL	NI	L	NI
8. Bic	NI	L	NL	NI	L	NI
9. Paper Mate Office Products Fine	I	NL	NL	I	NL	NL
10. Paper Mate Write Bros. Med. Pt.	I	NL	NL	I	NL	NL
14. General Kimberly #539 Med.	I	L*	NL	I	NL	NL
15. Faber Castell Sprit F-Blk.	I	L*	NL	I	NL	NL
Other:						
1. SC-UF Pilot Perm.	I	NL	NL	I	NL	NL
2. Pilot Razor Pt.	NI	L*	NL	NI	NI	NL
4. Pilot Fineliner	NI	L*	NL	NI	NI	NL
11. Flair	NI	L	NL	NI	L	NL
12. Excel	NI	L	NL	NI	L	NL
16. Eraser Mate 2 Fine Point	I	NL	NL	I	NL	NL
17. Sanfords Calligraphic Pen 2.5-mm	NI	L	NL	NI	L	NL
18. Sanfords Expresso	NI	L	NL	NI	L	NL
19. National Pen Co.	NI	L	NL	NI	L	NL
20. R100 Rolling Writer Pentel	I	NL	green	I	L	green
21. Pentel Super Ball	I	NL	green	I	L	green
22. Skilcraft 32	I	NL	NL	I	NL	NL
23. Pentel Stinger II	I	L*	NL	I	L	NL

[a]See Table 1 footnote for explanation of abbreviations.

and luminescence. Further, the color of the background and composition of the paper to achieve the proper color and surface as well have an effect on observed outcome of Model J and laser luminescence. Such differences may be related to inherent luminescing of the white paper, although examination of the Cascade paper alone revealed only a very low level of luminescence as compared to other types of paper under consideration for this research. Further, the lack of luminescence on the safety paper in some instances may be related to the absorbing properties of the color of the ink combined with the color of the paper.

No single nondestructive test alone can be relied upon to provide a correct conclusion regarding similarities or differences in inks. However, by using a series of nondestructive tests where consistencies or consistent differences are noted may bring the examiner closer to the facts of the situation. It is very important to take into consideration also the possibility of some contamination of the writing surface which would affect the masking properties of luminescence in inks that do not ordinarily luminesce. Nonuniformity of paper can result in

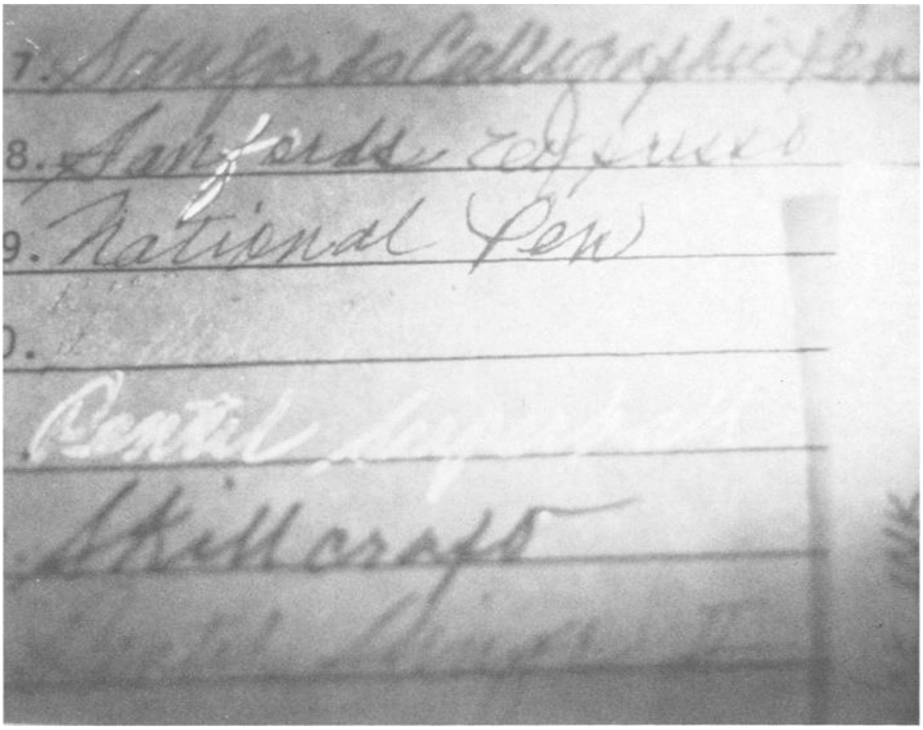

FIG. 3—*Luminescence on black inks 20 and 21 appeared bright green. When preparing new samples for photographing this luminescence, a "pen skip" on black sample No. 18 was mistakenly retouched using pen No. 21.*

ink from the same pen on the same paper differing in luminescence [*10*]. Observed results are for the time of examination only. In other words, overall, it is not possible to develop general "standards" predicting how certain inks might behave when processed with luminescing techniques.

However, examinations can proceed step by step, using any sequence or combination of nondestructive processes. For example, ultraviolet fluorescence, Model J reflectance and luminescence, and laser luminescence produced the *cumulative* differentiation of "other" red inks through each step described in Table 5.

Further study needs to be done in two areas: a comparison needs to be made between results obtained with the Nd:YAG Laser and the argon ion laser; and the comparison of luminescence over time needs further investigation. The change in the appearance of the two black Pentel inks over a period of about six weeks was unexpected. Subsequently, the original visual observations of all inks obtained through the use of the Model J and Nd:YAG techniques were rechecked, but were consistent with the original examination and tabulation.

An application for changes in luminescence over time is seen when a document is purported to have been signed by various parties at the same time and the chemical composition is consistent for all inks. Laser examination may show a difference in appearance, disputing the previous time claim. The same principle might apply to additions or interdelineations in holographic documents where such alterations purportedly occurred all at one time.

A cautionary note is also implied. If the writing were done at different times using the

TABLE 5—*Steps by paper type.*[a]

Cascade Paper		Dixon Paper	
Sample Number	Key	Sample Number	Key
Step 1: UV fluorescence		Step 1: UV fluorescence	
Sample 2	F	Samples 1, 2, 7	F
Samples 1, 3, 4, and 7	NF	Samples 3, 4	NF
Step 2: Model J reflectance		Step 2: Model J reflectance	
All samples	NI	All samples	NI
Step 3: Model J luminescence		Step 3: Model J luminescence	
All Samples	L	Samples 2, 7	F, NI, L
		Samples 3, 4	NF, NI, NL
		Sample 1	F, NI, NI
Step 4: Nd:YAG luminescence		Step 4: Nd:YAG luminescence	
Sample 2	F, NI, L, L	No further differentiation	
Samples 1, 4, and 7	NF, NI, L, L		
Sample 3	NF, NI, L, NL		

[a]See Table 1 footnote for explanation of abbreviations.

identical pen and ink formulation, the earlier entry may no longer luminesce while the later entry does. These results would suggest different ink formulations when, in fact, that might not be the case.

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