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TECHNICAL NOTE

Dual Mode Polarizing Pellicle

James R. Daniels

Forensic Document Examiner, 12 Greenway Plaza, Suite 1100, Houston, Texas 77046

This article describes techniques for using an angled glass pellicle to merge the path of light reflected from a sample with the line of view, permitting glare-angle lighting/observation view normal to the surface. Among other applications, reflective properties of ballpoint and some other writing inks, observed under such conditions, may permit determination of stroke sequence at intersections with other media.

Use of a polarizing pellicle rotated in its own plane permits the amount of glare from the specimen, or specularly reflected light, to be substantially varied relative to the diffusely reflected light. ("Pellicle" is a generic term for any thin plate, from the Latin *pellicula*, diminutive of pellis, skin. Various scientific disciplines borrow the term, chemistry using it to refer to surface crusts, optics using it to signify thin plates used as beam-splitters and the like.)

Described are both theory and practice of the geometry which simultaneously allows (1) illumination to impinge on the pellicle at Brewster's angle (which is a function of the refractive index of its glass), (2) reflection with polarization to the specimen surface at 90° thereto, and (3) 90° observation of that surface through the same pellicle functioning as a rotatable analyzer. The 1st reflection results in polarization entirely by reflection from the glass surface at Brewster's angle, whereas the rotating-analyzer function depends on the polarizing substance in the polarizer.

The technique does not require laboratory conditions and is applicable to field 35-mm photography in an office environment at the very low magnifications often most useful in document work.

Theoretical Conditions for Polarization by Reflectance (Figure 1)

Consider the case of unpolarized incident light at the air/glass interface at an angle Ø(i), reflecting at the angle Ø(r), where Ø(i) = Ø(r), or, angle of incidence = angle of reflection. Inside the glass, the light is bent by refraction to a different angle Ø(t) which depends on the refractive index of the glass with respect to air, in inverse proportion to the relative speed of light in the 2 media, according to Snell's law of the sines of the respective angles. Now resolve the electric vector of the light, which is always perpendicular to the direction of propagation of the light, into Cartesian coordinates, vertical and horizontal, such that the polarization vector is separated into vertical and horizontal components; and consider the vertically polarized component: there is a critical angle of incidence (= angle of reflection) at which the reflected ray is at right angles to the refracted, transmitted ray (inside the glass); at this angle, the electric oscillations of the transmitted vertically polarized component are parallel to the reflected ray. It is these very oscillations which actually generate the reflected ray; but, owing to the transverse wave nature of light, the electric vector cannot be parallel to the direction of propagation. Therefore, there cannot be a reflected ray, outside the glass, perpendicular to the (refracted) transmitted ray inside the glass, for this particular (vertically polarized) component. The other (horizontally polarized) component is freely reflected at this angle, however; and the light is therefore horizontally polarized with respect to the plane of the glass. This critical angle, named in honor of Sir David Brewster, is approximately 56° for glass/air, measured, not from the plane of the glass, but from the normal thereto. Although light reflecting from glass at this angle is completely horizontally polarized, the transmitted light is relatively enriched toward the other (vertical) polarization component only slightly; but multiple passes through glass/air interfaces at Brewster's angle eventually polarize

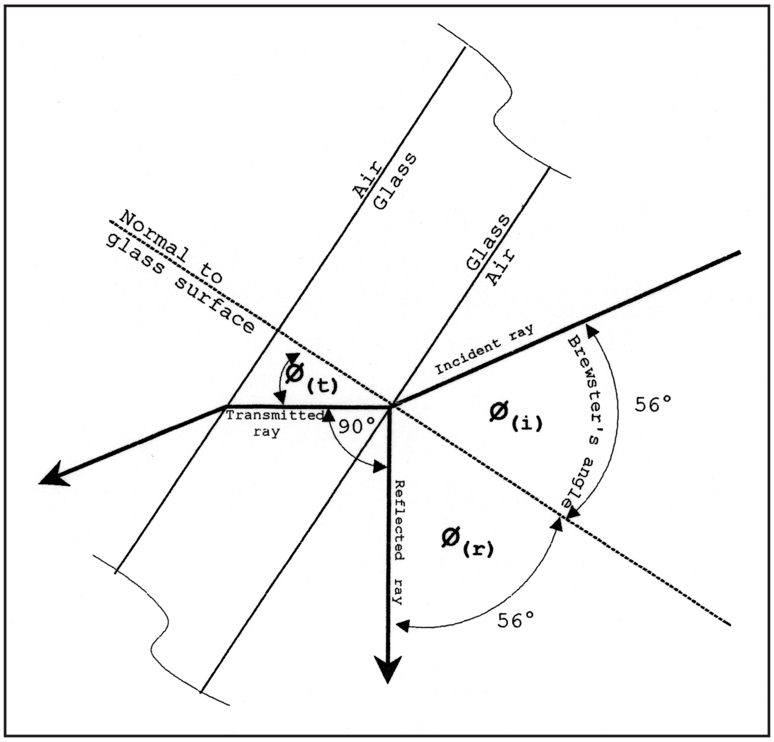

Figure 1. Interface Detail

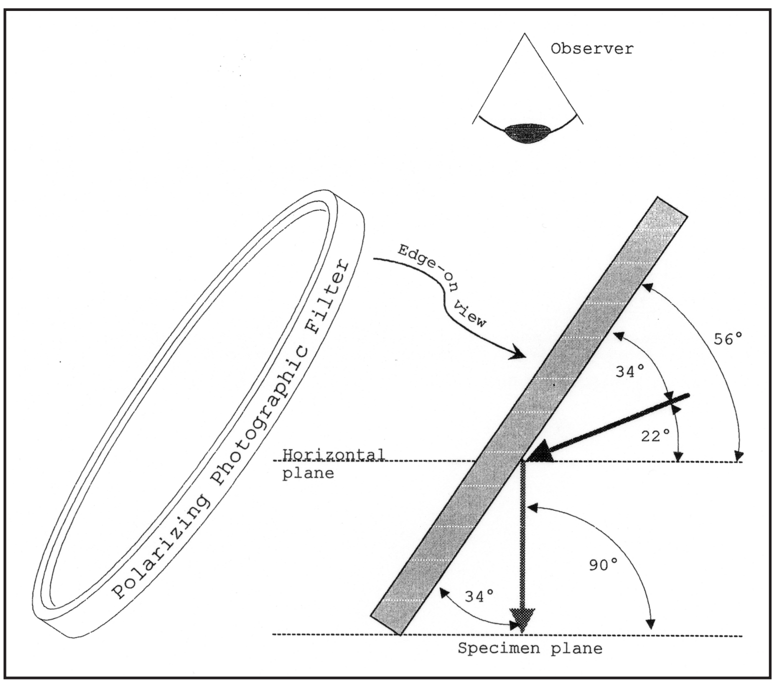

Figure 2. Overall Geometry

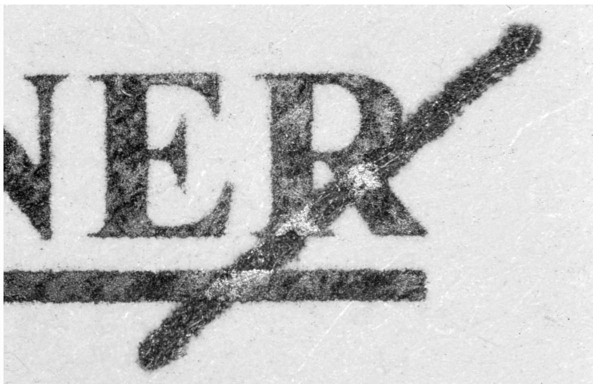

Figure 3. Reflection-enhanced macro showing characteristic glare behavior of a film of dried ink resulting from a written mark that had crossed over laser printing.

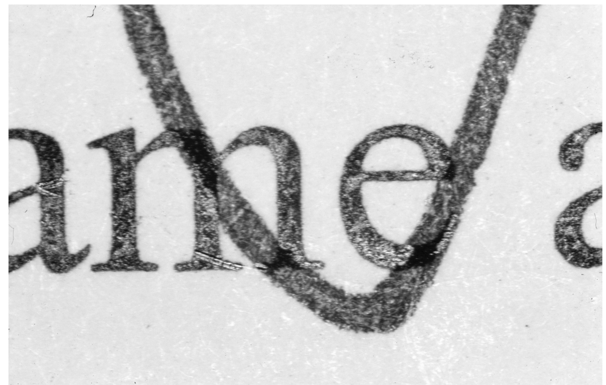

Figure 4. Reflection-enhanced macro showing characteristic absence of gloss of unfused toner resulting from laser printing over pre-existing moderately embossed ink line.

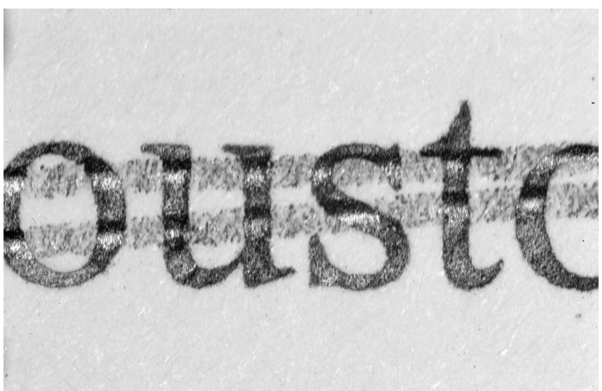

Figure 5. Enhanced-glare macro of ballpoint lines written over laser printing, showing burnished embossments.

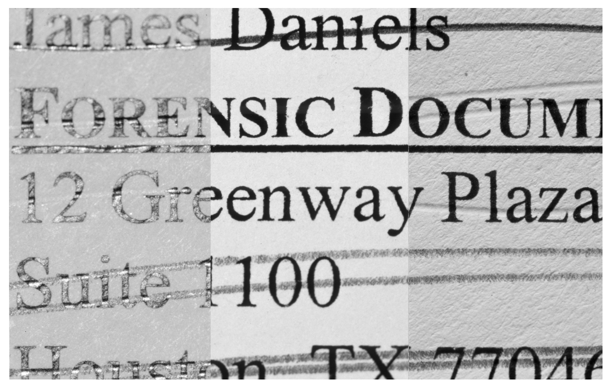

Figure 6. Lines written over laser printing. Left: Glare-enhancing polarizer position. Middle: Glare-suppressing position. Right: Raking-lighted reference. Top: Black fluid ink line. Middle: Dry pen embossments. Bottom: Black ballpoint lines.

the transmitted beam also, by stepwise attrition through reflection losses of the horizontal component, a condition which exists in many lasers which do finally emit a highly polarized beam. In other words, the reflected beam, although consisting of the horizontal polarization only, is reflecting from a medium which is, after all, transparent, and even the horizontally polarized component is only partially reflected. And, although reflection of the vertical component is entirely suppressed, there is not a total reflection of the horizontal component. (Thankfully, because the method under discussion would fail: the horizontally polarized pellicle-reflected light would reflect off a shiny subject, preserving its polarization, and, in re-encountering the pellicle, again at Brewster's angle, this time from below, would be entirely reflected back toward the illuminator and not pass through the to the analyzing polaroid material on its way to the observer, defeating the purpose of the technique.)

Incidentally, the reflecting/refracting medium must be a dielectric such as glass, not a conductor such as a semi-silvered (metallic) surface, because of the metal's abundance of electrons free to move near the surface, permitting perpendicular oscillation of the electric vector at any reflected beam angle and therefore not suppressing the Brewster angle reflected ray.

Technique (Figure 2)

A single-lens reflex camera body and flat-field macro or enlarging lens are mounted on a bellows and macro stand with an open base through which the subject document may be photographed. (For nonphotographic observation, a special conversion eyepiece is substituted for the camera body; or a stereo microscope or long-focus magnifier may be substituted for the entire camera setup.) A plane-polarizing glass filter is interposed as a pellicle between the observer and the horizontal specimen, at an angle of 56° to the horizontal. A collimated beam of light is directed (at a downward angle of 22° from the horizontal) at the center of the pellicle so as to reflect onto the portion of the document being viewed. The image, as seen through the camera viewfinder, is focused by adjusting the bellows. The reflective behavior of the specimen is examined as the pellicle is rotated in its own plane. Any specular reflections (even metallic ones) or glare may be selectively diminished or enhanced depending on this rotational adjustment. At the minimum-glare position, there is an interesting but unreal quality to the image, in that the subject is being simultaneously illuminated and viewed at the normal (90°), yet all the intuitively expected reflections are suppressed. At this position, shiny toner particles and inks are rendered absolutely "dead," lacking normal highlights. As the pellicle is rotated from this reflection-deadening position through 90°, any surface shine increases from 0 to a maximum. It is at this reflection-enhancing position that the characteristic glare behavior of certain inks applied over a black substrate (such as photocopier toner, printing ink, or typewriting) is optimized for photography. From a purely observational standpoint, the ability to rapidly vary the intensity of these highlights (by rotating the polarizing pellicle back and forth) greatly aids the human eye in distinguishing the specular contribution to such highlights such as from inks exhibiting their thin film "bronzing" behavior from merely bright or light colors. For illustrations see Figures 3-6.

The light source does not have to be highly collimated, if, as usual, the detail of interest is centered in the field of view. Of course, the specimen should be shielded from direct exposure to the light source and illuminated only by the reflected light bounced from the pellicle.

The specific angles of the pellicle and light source given here assume a commonly given literature value of Brewster's angle for glass, doubtless dependent on an average glass/air refractive index for the wavelength of the yellow sodium D-line of light. My own calculations, optimized for the high quality optical glass used in photographic filters, and using a nominal wavelength of 550 nanometers, give values of 53° pellicle inclination and 16° illumination angle, both measured from the horizontal. Although Brewster's angle, being a function of the refractive index of the pellicle glass, varies slightly with wavelength at a rate depending on the dispersion of the glass, this consideration is negligible for this application.

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