

# Instant Imaging

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## Abstract

Instant imaging was born fifty years ago when E. H. Land set out the goals for "one-step photography" and demonstrated the first instant photographic systems. Since that time, Polaroid, Eastman Kodak, and Fuji Photo Film have developed silver halide-based products with similar "instant" characteristics. The technical highlights of these black-and-white and color diffusion transfer systems are reviewed. The unique characteristics of these imaging products are compared with the original goal for instant imaging. Finally, the gaps between that goal and alternative technological approaches are noted.

## Introduction

The goal of this symposium in which this paper is presented is to review fifty years of progress in imaging science and technology as a way of celebrating the fiftieth anniversary of this society. By coincidence, fifty years ago Polaroid first demonstrated instant photography. While the range of imaging applications addressed by instant imaging has broadened considerably since that time, it is enlightening to consider Edwin Land's original goals<sup>1,2</sup> for instant imaging, especially in light of the topics in today's symposium:

"To make it possible for the photographer to observe his work and his subject matter simultaneously, and to remove the manipulative barriers between the photographer and the photograph...so that the photographer by definition need think of the art in *taking* and not in *making* photographs."<sup>1</sup>

Land also explained that his approach to this goal was to specify that

"the picture must be available promptly after it is taken, and must be large enough for evaluation. The characteristic curve of the overall process must be so chosen as to lend itself to recording scenes in haze, sunshine, and shadow, as well as by flash-light. The resolving power of the total system must be beyond the demands of the eye for the chosen size of picture. The final image must be stable. The camera should be as small and as light as is consistent with the picture size chosen, and should be dry and easy to load. The process must be reliable, safe, dry or apparently dry, and behave well over a wide range of ambient temper-

atures and relative humidities....In short, all that should be necessary to get a good picture, is to *take* a good picture..."<sup>1</sup>

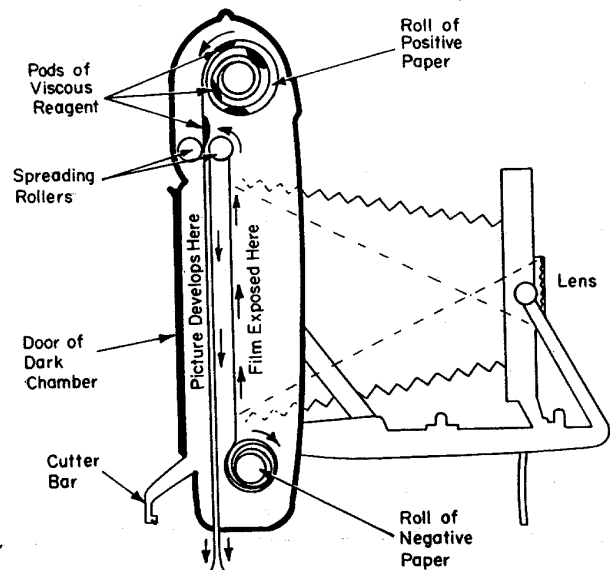


Figure 1. Schematic of Polaroid Model 95 camera (1948). After exposure, pulling a leader brings the negative and positive sheet (to which the pod is attached) together through the rollers, rupturing the pod, and spreading the viscous reagent between the two sheets. After the processing period, the user opens the door of the dark chamber and peels off the positive print (Ref. 6, p. 282).

## Evolution of Instant Photography

While this paper traces the evolution of approaches to Land's goal, it is interesting to bear in mind that goal as we consider the other topics covered in today's symposium. The publications cited above followed commercial introduction of "one step photography" as embodied in the Polaroid Model 95 camera and Polaroid Type 40 roll film. In this initial system (shown schematically in Figure 1), the camera incorporated a pair of rollers, a dark chamber, and web handling mechanisms. The user initiated photographic processing by pulling the film through the rollers in order to break a rupturable envelope or pod containing viscous processing reagent and spread it between the negative and the image-receiving sheet. The developing image was stored in the camera's dark chamber for a user-determined time, after which the user removed the sandwich and peeled the finished

sepia image away from the negative as shown schematically in Figure 2. Exposed silver halide grains develop to silver metal as in conventional negatives. However, unexposed silver halide grains dissolve via action of a "silver solvent" (such as hypo). The soluble silver complexes diffuse through the film structure to the receiving sheet where nuclei such as zinc sulfide catalyze their reduction to the silver metal, which forms the positive image. While others<sup>3</sup> had also explored this type of diffusion transfer imaging, this was the first application using small, handheld cameras and pod<sup>4</sup> vs. bath processing. Indeed, Land believed that the pod might have been his most significant invention (Figure 3)<sup>5</sup>.

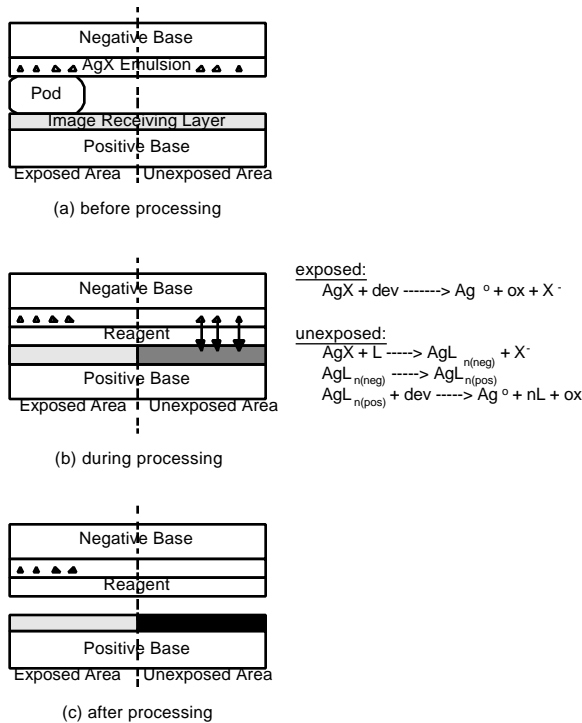


Figure 2. Schematic cross section of black-and-white peel-apart one-step film. (a) Before processing. (b) Viscous processing reagent spread between negative and receiving sheets during processing. (c) After processing the two sheets are peeled apart to reveal positive image on receiving sheet.

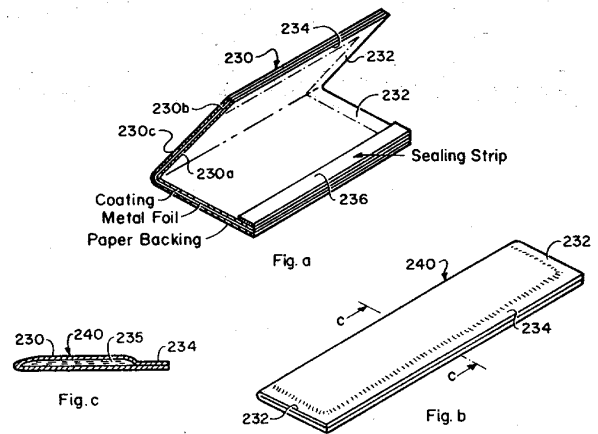


Figure 3. Illustration from U.S. Patent 2,543,181 showing typical pod design.

In 1950, Polaroid introduced Type 41 film that gave black-and-white, neutral tone images. In changing from sepia to black images, the positive nucleating layer was extensively investigated.<sup>7</sup> Both chemical and physical phenomena control tone to the final image. Figure 4 shows micrographs of sepia and neutral tone positive silver deposits from an early Polaroid transparency film.

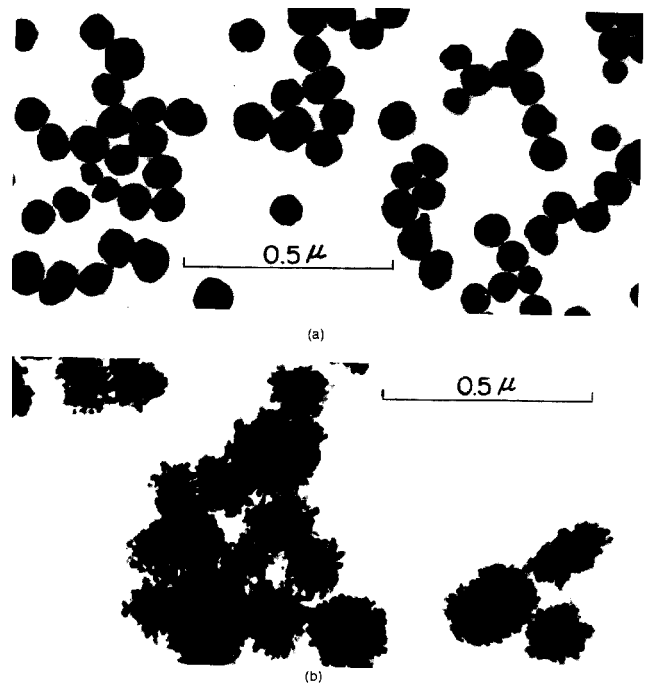


Figure 4. Silver metal image deposits from sepia transparency film (upper) and from black transparency film (lower)(Reference 6).

In 1961 the dark chamber-in-the-camera/roll film format gave way to pack film with the Model 100 (Figure 5). In this case the film develops in a light-tight package outside of the camera and permits a somewhat more compact camera design. The Model 100 camera provided additional innovations such as controlling exposure duration by integrating light measured during exposure.

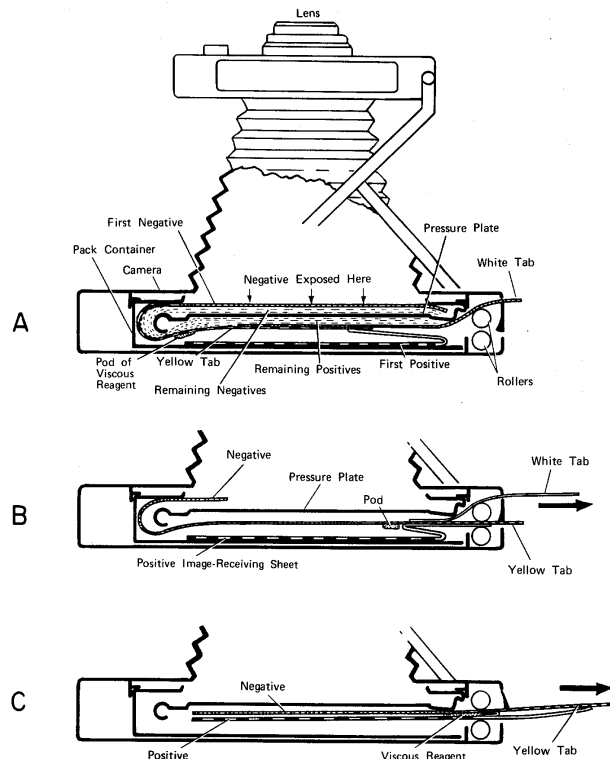


Figure 5. Schematic cross section of Polaroid Model 100 camera (1963) showing pack film processing sequence (Reference 6, p. 283).

In 1963 Polaroid introduced a color version of the instant pack film. After considering how to create multi-color instant images, Polaroid's Howard Rogers ultimately settled on the dye-developer concept (Figure 6).<sup>6</sup> An additional challenge for these images was stability. Here pH was a deciding factor. Furthermore, considering Land's goal quoted above, it was undesirable to continue to require users to swab their images with a stabilizing fluid. As a consequence Polaroid developed timing layers and acid layers. In order to stabilize color images, the system needed to be brought to a significantly lower pH than that of the reagent. A polymeric acid layer could accomplish this. However, the system needs time to develop and for dye developers to be either insolublized by oxidation or transferred to the receiving sheet. Hence, the need for a timing layer that introduces a delay in the pH drop. Another important element was the image receiving layer or mordant, which has a dramatic impact on image quality in terms of sharpness and stability. Figure 7 shows a schematic drawing of a Polacolor negative.

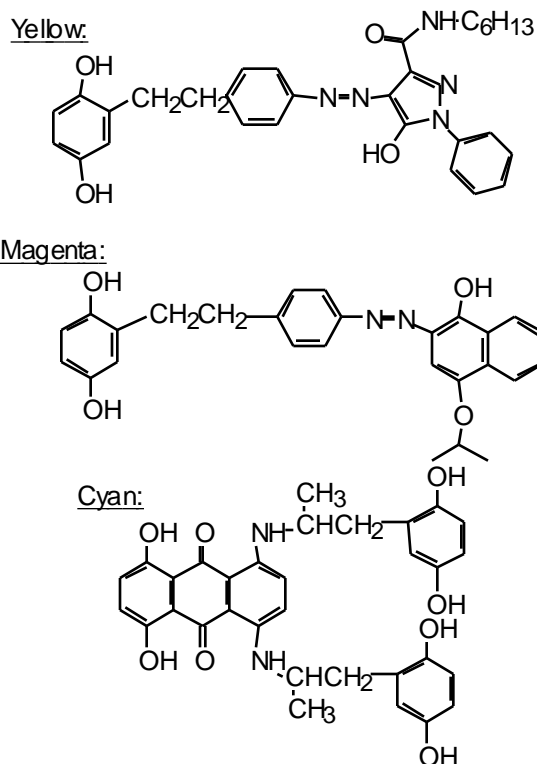


Figure 6. Early Polacolor dye developers.

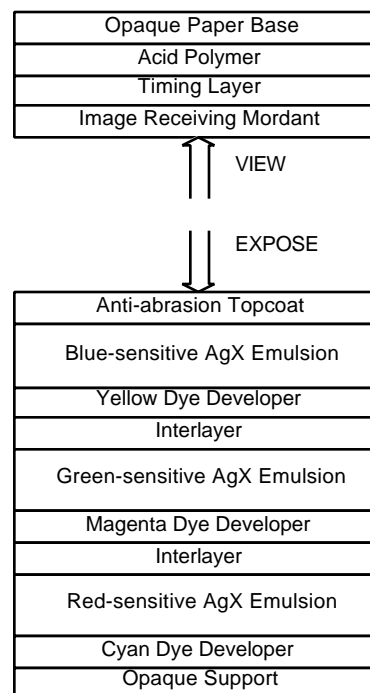


Figure 7. Schematic cross section of Polaroid Polacolor positive and negative sheets. Viscous alkaline reagent is spread between the two during processing. In unexposed areas dye developers diffuse through to the receiving layer. After processing for 60 seconds, the sheets are stripped apart to reveal the positive color print in the receiving sheet.

Having a method to automatically drop the system pH and thereby shut down processing and then stabilize images allowed instant photography to come closer to Land's original goal. In 1970, similar technology was extended to black-and-white peel-apart systems resulting in coaterless black-and-white Type 107C.

But, in fact, calling peel-apart instant photography—even coaterless—"one step" photography was, perhaps, a bit of hyperbole: after exposure the user still needed to pull two tabs, time processing, peel off the finished positive, and dispose of the spent negative/pod assembly. As we know, the 1972 introduction of Polaroid's SX-70 camera and film system brought instant photography dramatically closer to Land's original goal. In articles titled "Absolute One-Step Photography," Land described what we call integral instant photography.<sup>8,9</sup> In this system, the picture is automatically ejected from the front of the camera within four hundred milliseconds of completion of the exposure. "The picture is hard, dry, shiny, flat—and invisible.... Since the picture emerges from the camera directly into the light, with nothing to be peeled away, the photographer has the opportunity to observe the whole process of materialization. The photographer is not concerned with wet processing of negatives or timing of prints because the picture from this camera is hard and dry, and because the materialization reaches its final color values asymptotically; therefore, he is free to take his next picture as soon as he wishes. Indeed, he may take one about every 1.3 sec."<sup>9</sup>

In moving to the integral print SX-70 system both camera and film were dramatically re-engineered. The camera (Figure 8) was a radically designed close-focusing, folding, single lens reflex device of unprecedented compactness for instant photography.<sup>10</sup> It incorporated two mirrors, an aspheric aperture element, and an aspheric eye lens. The body employed a new thin plastic stiffened and made attractive by a thin metal coating. The system used motorized film transport and was one of the first cameras to use integrated circuits to control the exposure process. In order to insure reliable operation, a novel flat battery which powered camera electronics, motor drive, and flash was built into every pack of film.

If the camera needed to learn new tricks for integral instant photography, so did the film. Mechanically, integral film needs to prevent caustic reagent from leaking out, enable smooth spreading of reagent evenly across the negative over a wide temperature range, hold the negative flat in the film plane during exposure, and present an aesthetically pleasing final format for displaying photographs. Chemically, integral film needs to permit exposure of the negative by light passing through the camera's shutter, yet immediately after—as the negative ejects from the camera into light levels as much as several million times brighter—prevent light from reaching the negative. Perhaps the greatest challenge of the SX-70 system was the design of such an "opacification" system.<sup>11</sup>

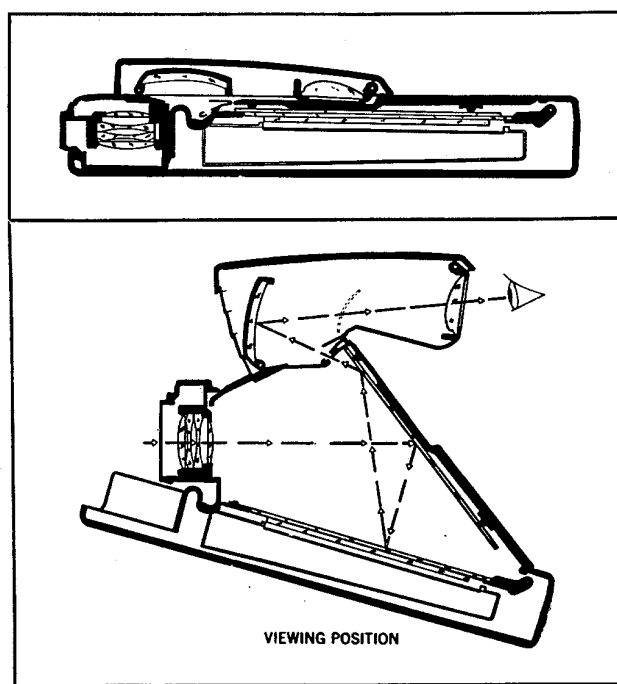
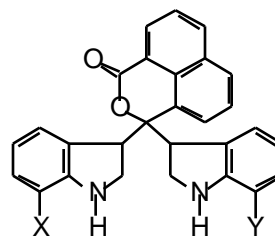


Figure 8. Cross section views of Polaroid SX-70 camera shown in folded position and in open position with SLR light path during focusing and composition of an image (Ref. 9).

This system involves white titania suspended in the alkaline reagent which ultimately serves as a white background to hide negative and against which the final picture is viewed. Because titania alone does not provide sufficient optical density to prevent exposure of the film as it ejects from the camera, special indicator, or opacifying, dyes are used. These dyes have quite high extinction coefficients across the visible wavelength range at high pH yet are substantially uncolored at the lower pH of final images (Figures 9 – 11). In addition, new, more light-stable metallized image dyes were introduced in SX-70 (Figure 12).<sup>9</sup> Schematically, the function of the SX-70 dye developer system is illustrated in Figure 13.



X	Y	pKa
H	H	11.1, 13.8
COOH	COOH	13.2, >15
COOH	NHSO <sub>2</sub> C <sub>16</sub> H <sub>33</sub>	12.9, >15
COOH	SO <sub>2</sub> NHC <sub>18</sub> H <sub>37</sub>	12.9, >15

Figure 9. Effect of hydrogen bonding substituents in positions X and Y on pKa values of a series of naphthalein opacifying dyes (Reference 6).

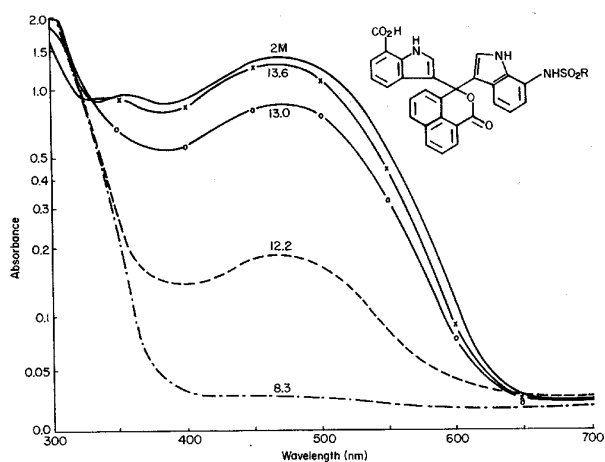


Figure 10. The pH dependence of the absorption spectrum of a naphthalein opacifying indicator dye in solution. The dye is very colored at high pH but close to colorless at pH 8.3 (Reference 6).

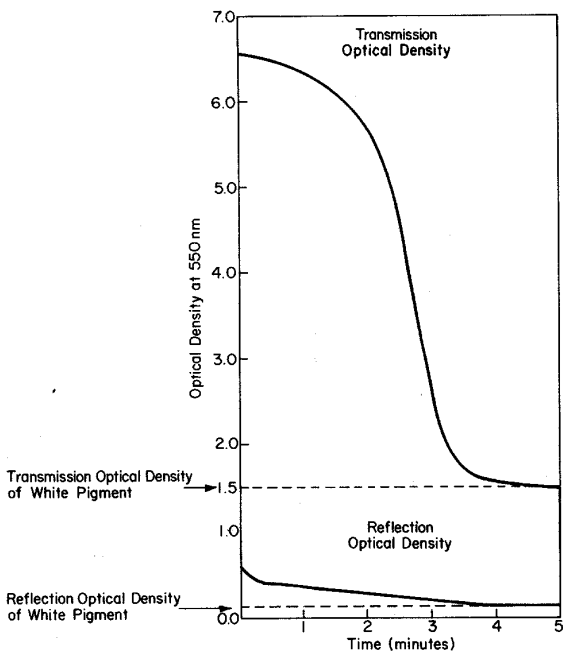


Figure 11. Transmission and reflection densities as a function of time after spreading for an opacifying reagent system. Image dyes diffusing to the receiving layer are visible against an adequately light background (low reflection density curve) while the still-reactive negative is protected from light outside the camera (high transmission optical density curve)(Ref. 6).

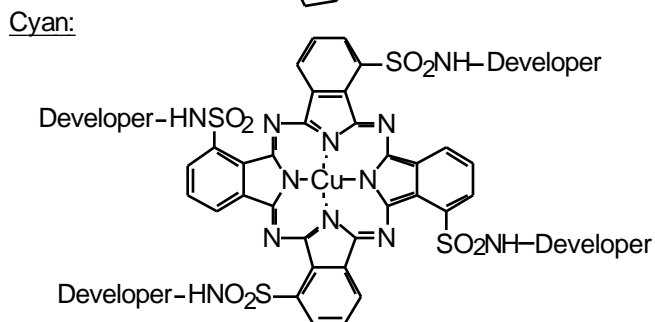
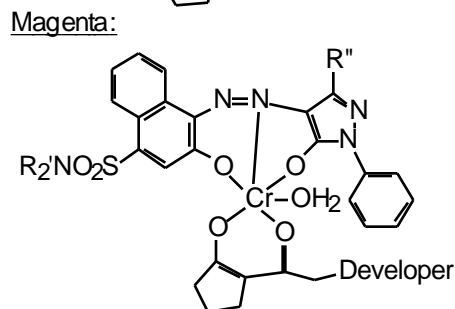
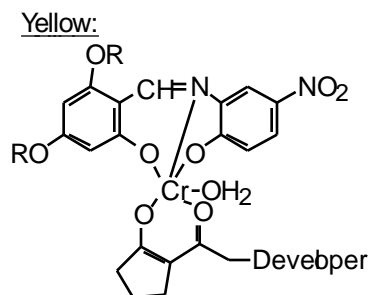


Figure 12. Metallized dye developers introduced in Polaroid SX-70 film.

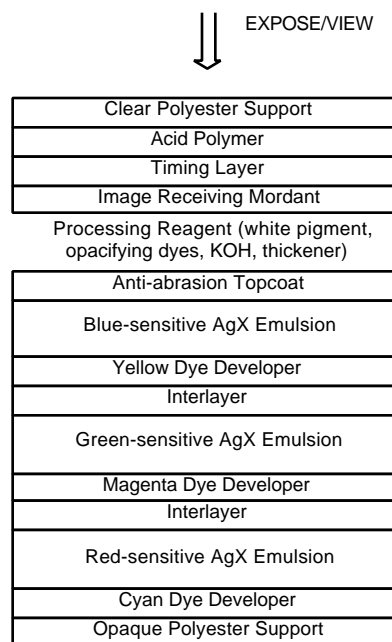


Figure 13. Schematic cross section of Polaroid SX-70 integral film showing negative, reagent spreading area, and imaging receiving sheet.

In 1976 Kodak introduced color integral instant film, PR-10.<sup>12</sup> Rather than dye developers, PR-10 employed direct positive silver halide emulsions and oxidative release of pre-formed dyes (Figure 14). In addition, PR-10 used a film structure (Figure 15) where exposure and viewing occurred on opposite sides of the film unit. This results in somewhat slower image emergence but eliminates the need for opacification dyes since simple carbon black can be spread from the reagent to create the "darkroom" during processing.

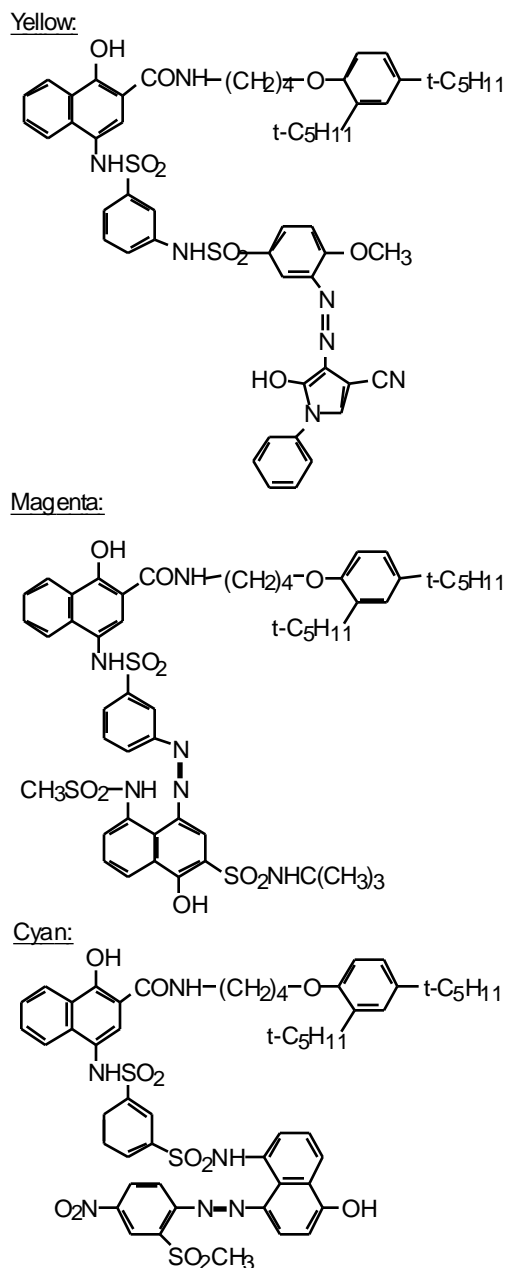


Figure 14. Oxidative dye release compounds from Kodak PR-10 color integral instant film (ref. 16, pp. 198-199).

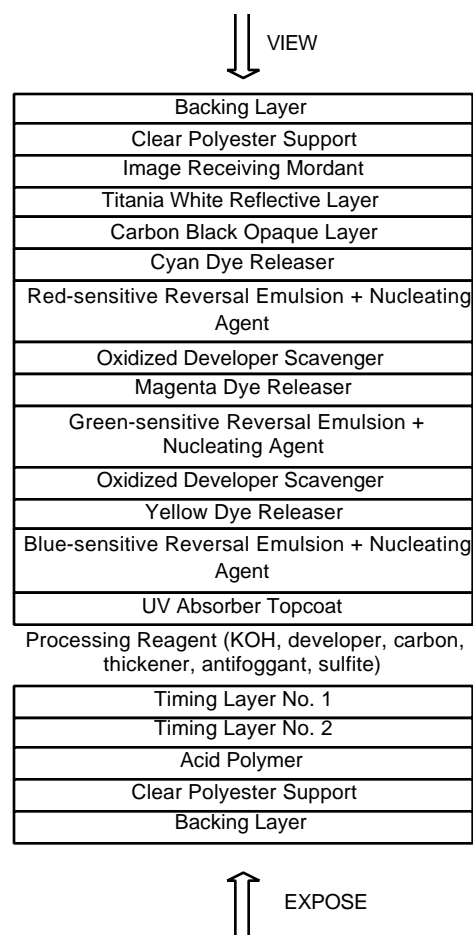


Figure 15. Schematic cross section of Kodak PR-10 integral instant film showing image forming and receiving sections of the negative, reagent spreading area, and cover sheet with timing and acid layers (ref. 16, p.207).

1979 saw Polaroid's introduction of automatic sonar range finding into the folding SX-70 camera, which further simplified the photographer's task. In addition, the company launched TimeZero film, with faster image emergence and better color reproduction. In 1981 Fuji Photo entered the instant imaging market via FI-10 color integral instant film with a similar design to Kodak's PR-10.<sup>13</sup> Also in 1981, Polaroid introduced a faster film speed version of integral film known as the 600 line. 1983 saw Kodak's introduction of Trimprint integral film. This product allowed users the option of stripping away the completed image from the rest of the film assemblage in order to give a thinner final print. In 1984 Fuji Photo introduced a faster film speed version of its integral film (FI-800) and also entered the peel-apart markets with Polaroid hardware-compatible color and black-and-white pack films. In 1986 Polaroid introduced the Spectra system.<sup>14</sup> In order to improve image quality by minimizing undesirable interimage effects, Polaroid combined cyan and

magenta dye developer systems (Figure 13) with a silver ion-assisted yellow dye release chemistry (Figure 16).<sup>15</sup> The Spectra system moved to a rectangular film format and employed a novel quintic lens system in the camera. Further evolutionary improvements by both Polaroid and Fuji have continued to increase the image quality of these integral instant-imaging products.

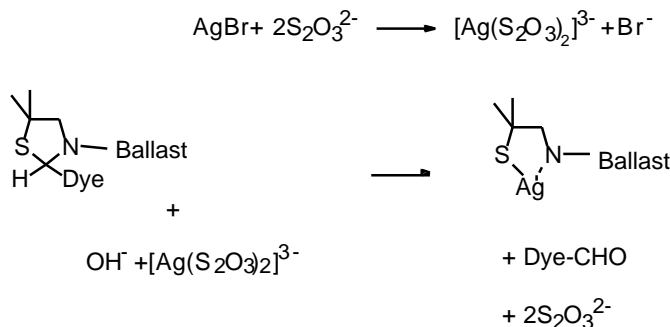


Figure 16. Silver ion assisted dye-release chemistry in unexposed areas of the blue-sensitive sandwich of Polaroid Spectra film (ref. 15).

### Other Instant

This paper has focused on consumer, handheld instant imaging—the products attempting to meet the goal articulated by Land in the 1940s and quoted at the opening. There have been many adaptations of diffusion transfer photography for other applications. Many are derivatives of the instant imaging products mentioned above, such as Polaroid large format 20" × 24" Polacolor, Kodak Ektaflex<sup>16</sup> single bath color media, and Fuji Pictography<sup>17</sup> color photothermographic office systems. Others were developed specifically for their application and fall under diffusion transfer if not instant imaging. For example, Agfa's Agfachrome Speed<sup>18</sup> single bath print paper and Fuji Pictostat<sup>19</sup> color photothermographic copier systems. However, these products address areas covered by other papers in this symposium (hybrid imaging, hardcopy) and compete with other technologies (e.g., dye diffusion thermal transfer, inkjet, Thermal Autochrome).

### Conclusion

Returning one more time to Land's goal and broad specifications for instant imaging, we can readily list areas for further improvements to today's instant photographic products. We also realize that for all of its attraction and

promise, electronic and hybrid imaging products today are closer to the state of photography prior to Polaroid's introduction of instant photography—sophisticated equipment (much not portable) and skilled users are required to make a beautiful print, however easily the image is captured. The challenge remains.

### References

1. Land, E.H. *Photogr. J.*, A, **1950**, 7-15.
2. Land, E.H. *J. Opt. Soc. Amer.*, 1947, **37**(2), 61-77.
3. Rott, A.; Weyde, E. *Photographic Silver Halide Diffusion Processes*, Focal Press, London, 1972, and references therein.
4. Land, E.H. U.S. Patent 2,543,181 (1951).
5. Mervis, S.H. *Optics and Photonics News*, 1994, **5**(10), 50-53.
6. Land, E.H.; Rogers, H.G.; Walworth, V.K. in *Neblette's Handbook of Photography and Reprography*, seventh edition, Sturge, J.M. (ed.), Van Nostrand Reinhold Co., New York, 1977, p. 307.
7. Ref. 1b pp. 11-13 and Land, E.H.; Walworth, V.K.; Corley, R.S. *Phot. Sci. Eng.*, 1972, **16**(4), 313-315.
8. Land, E.H. *Phot. Sci. Eng.*, 1972, **15**(4), 247-252.
9. Land, E.H. *Photogr. J.*, 1974, **114**(7), 1-7.
10. Plummer, W.T. *Appl. Optics*, 1982, **21**(2), 196-202.
11. Simon, M.S. *Dyes and Pigments*, 1989, **11**, 1-12; and Simon, M.S. *J. Imaging Technol.*, 1990, **16**(4), 143-145.
12. Hanson, W.T. Jr. *Phot. Sci. Eng.*, 1976, **20**(4), 155-160.
13. Fujita, S.; Koyama, K.; Ono, S. in *Reviews on Heteroatom Chemistry*, vol 7, Oae, S. (ed.), MYU, Tokyo, 1992, 229-267.
14. Lambert, R. *J. Imaging Technol.*, 1989, **15**(3), 108-113.
15. Meneghini, F. *J. Imaging Technol.*, 1989, **15**(3), 114-119.
16. Walworth, V.K.; Mervis, S.H. in *Neblette's Imaging Processes and Materials*, eighth ed., J. Sturge, V. Walworth, and A. Shepp (eds.), Van Nostrand Reinhold, NY, 1989, p. 221.
17. Aotsuka, Y.; Hara, H.; Sato, K. *SPSE 41<sup>st</sup> Ann. Conf.*, 1988, Washington, D.C.
18. Peters, M. *J. Imaging Technol.*, 1985, **11**(3), 101-104.
19. Yokokawa, T.; Sawada, S.; Nakamura, K. *Intl. East-West Symposium III, New Frontiers in Silver Halide Imaging*, 1992, Hawaii, pp. D1-D5.