The Matterhorn photographed in color by Gabriel Lippmann between 1891 and 1899.

Collection Photo Elysée / Fonds Lippmann

LIGHT TOUCH

Lippmann's Unfading Photographs

Stephen R. Wilk explores a technique that leverages interference to create vibrant, stable color pictures—but never hit the mainstream.

I first encountered a Lippmann photograph in the George Eastman Museum of Photography in Rochester, NY, USA. It was a tiny thing, illuminated by a bright light in the front. You could only see the image from a narrow viewing angle, but when you did, it blew you away. It was "The Garden at Versailles," an image captured by the technique's namesake Gabriel Lippmann himself in 1900. Remarkably, it still displayed the red and blue flowers and the blue sky in vibrant color. It was so completely unlike other early color photographs in its unfaded and accurate color that I needed to learn more.

This method for capturing images was never covered in any of my courses at the University of Rochester's Institute of Optics, but the institute had plenty of resources. I quickly became aware of several unique features about this type of photography: Since it used no dyes or pigment, its colors would remain bright and never fade. Since it did not rely on the tristimulus system (which visually matches a color against the three primary colors), the colors it reproduced were not bound by any triangular gamut of colors, but could in principle reproduce any point bounded by the spectral locus on a CIE (International Commission on Illumination) color diagram. And because of the way it was produced, making and properly viewing such an image was very difficult, and required a viewing light source very similar to the one used to record the image.

Nevertheless, this seemed like an ideal medium for archival storage of images, where the need to record and preserve accurate color images was paramount. I was surprised that this technique was not better known, but I was not at all surprised that Lippmann had been granted the 1908 Nobel Prize in Physics for his achievement.

Of course, nothing is perfect. Lippmann photographs are not accurate spectral reproductions of the original images. Furthermore, taking the images used to require the use of toxic mercury, and it certainly does require the use of extremely fine-grained emulsion, along with a great deal of care to minimize expansion and swelling in the critical thin volume of the emulsion where the image is stored. Despite all of these obstacles, there has lately been a renewed interest in Lippmann imaging, and new materials are being used.

Attempts to capture color

The colors in Lippmann photography are the result of interference bands captured in the emulsion. The idea of capturing these bands did not spring full-blown into Lippmann's mind, but was inspired by experiments and inferences made during the 19th century. Interference and diffraction were put on a mathematical basis by Fresnel, Fraunhofer and others, and their role in producing color was well-documented.

In 1810, German physicist Johann Thomas Seebeck found that if he exposed paper treated with silver nitrate to the light from a spectrum created by a prism, it showed faint colors similar to those used to create the image. The colors were indistinct, and they faded with time and exposure to light. In 1840, photography pioneer John Herschel found that if paper treated with silver chloride solution and "blackened in the sun" was then exposed to blue or red light, the paper would assume that color. But, again, the effect disappeared with continued exposure to sunlight.

Self-portrait of Lippmann viewed under diffuse illumination (left) and directed light (right).
G. Baechler et al. / Proc. Natl. Acad. Sci., 2021; CC-BY-4.0

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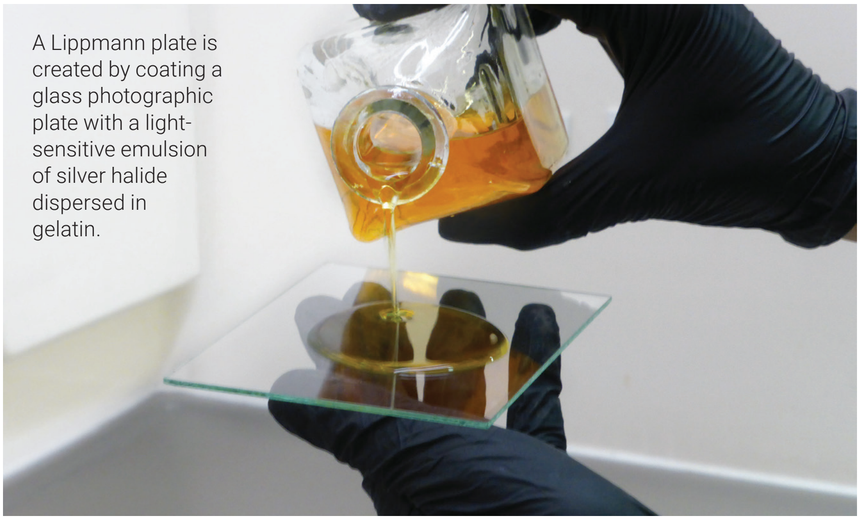
In 1848, French scientist Alexandre-Edmond Becquerel performed a more ambitious experiment with a mixture of silver chloride and silver subchloride, recording a spectral image that has been preserved to this day. He also produced some color photographs, but these were unstable and again faded if exposed to light. Aside from Becquerel's short-lived images, these efforts dealt with reproducing individual colors in a spectrum, not reproducing entire scenes in a variety of colors, which was Lippmann's goal.

Leveraging a mercury mirror

Lippmann, who was a professor of mathematical physics at the Sorbonne in Paris, began by attempting to fix the colors of the solar spectrum on a photographic plate in 1886. By February 1891 he had succeeded, and he announced his discovery to the French Academy of Sciences on 2 February. Throughout that year, he experimented with making color images of brightly and vari-colored objects, such as stained glass windows, national flags, fruits and flowers and, most famously, a stuffed parrot. He explained his process in papers published in 1894 and 1906.

Lippmann used a backing of mercury as a deformable mirror that hugged the shape of the emulsion and allowed a reflected beam from the original illuminating beam to interfere with itself. Because the coherence length of natural white light is so very short—only a few wavelengths—the depth of the region in which the interference pattern is written in the emulsion is similarly short. This explains the need for the mercury as



A Lippmann plate is created by coating a glass photographic plate with a light-sensitive emulsion of silver halide dispersed in gelatin.

C. Teixidor Cadenas / Wikimedia Commons; CC-BY-4.0

a mirror and the extremely fine grain of the emulsion.

The pattern of lamellae (as the interference planes are called) was then fixed with the same techniques as for ordinary negatives, but using chemicals that would not cause swelling or deformation of the fragile emulsion. Lippmann then illuminated the photograph from the front, eliminating retroreflection and glare from the front surface of the photographic plate by adhering a glass wedge atop the original plate with index-matching cement.

His work quickly excited the interest of others. Experimenters produced their own ultra-fine-grain emulsions and tried various developing agents that would preserve the thickness of the emulsion. Lippmann never patented the process, and he described his methods fully, making the principles available to anyone who wished to invest the time and effort. But the process was not easy to master, and although interest among a few enthusiasts was high, it was not a popular practice. Three-color methods of color photography were much simpler to exploit and could be reproduced, printed and distributed, so they came to dominate the market.

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A Lippmann renaissance

Interest in Lippmann photography was renewed in the 1960s, when Emmett Leith and Juris Upatnieks began making 3D holograms using lasers with long coherence lengths. Since holography also demanded fine-grained emulsions to record interference patterns from visible light, the media necessary for making Lippmann photographs were available again. Lippmann photographs differ from holograms because the interference waves are pegged to the emulsion surface, therefore losing phase information.

Now, a sort of second renaissance of Lippmann photography has begun. Articles by Gilles Baechler and colleagues at the Ecole Polytechnique Federal de Lausanne, Switzerland, have demonstrated that the deficiencies in accuracy of recording the interference fringes means that the spectral colors in Lippmann photographs are not quite perfect reproductions of the original colors. They do, however, record information about the spectral content that can be used to recover the original source spectrum—a case of century-old hyperspectral recording.

In addition, new materials have come along, inspired by the possibilities of holography. Photopolymers are now available as a fine-grain emulsion to use for recording. The use of mercury, a toxic material, has long been abandoned by those making Lippmann photographs, and they instead leverage the Fresnel reflection between the emulsion and the air to create the reflected wave. However, the Fresnel reflection coefficient is much smaller than the almost-perfect reflection one gets from mercury. A very promising alternative appears to be Galinstan, which is a gallium-based eutectic that is liquid at room temperature. The main difficulty in Galinstan-based Lippmann techniques appears to be the creation of gallium oxide when the alloy is exposed to moisture.

A definitive application for the method is still elusive. No one seems to be pushing for its use for archival storage. One proposal has been made to use the process to create hard-to-counterfeit secure documents. Benjamin Miller and Mathias Kolle, with the Massachusetts Institute of Technology, USA, have used Lippmann's techniques to produce images on large-scale stretchable sheets for monitoring stress or temperature through color changes. But the Lippmann photograph appears, like the laser in its early days, to be a solution in search of its optimal problem. OPN

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