The edible hologram

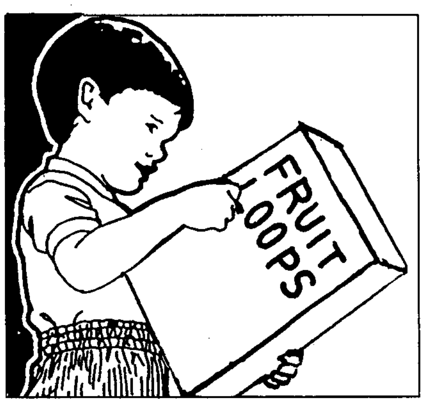
There is a popular misconception that the mass produced holograms affixed to credit cards and Fruit Loops cereal boxes are reflection holograms. Despite the fact that the viewer and light source are on the same side of the hologram, a basic distinction in the classification of holographic gratings is missed.

When a photosensitive emulsion is placed directly between two mutually coherent sources (henceforth referred to as position "A"), it records a standing wave pattern and the interference contours are separated by one-half wavelength.[1] A photosensitive emulsion that is placed off to the side (position "B") records Young's fringes with a coarser fringe spacing. In both cases, the processed photoemulsion is often described as containing partially reflecting mirrors situated along the regions of constructive interference.

Position "A" corresponds to a true hologram. It relies on Bragg diffraction and is sometimes called "Denisyuk" hologram after its inventor. Provided the emulsion has not shrunk during processing and the relative positions of the hologram and reference beam are unchanged, the image will appear in the color it was recorded at. This is true even if the reference beam is replaced by a white light point source, since all other colors suffer destructive interference. The grating exists within the volume of the hologram and is not accessible for replication by embossing.

Position "B" represents a transmission hologram. These can be viewed in reflection after coating one side with aluminum and illuminating the hologram from the viewer's side. These pseudo-reflection holograms do not have the color selection of true reflection holograms, but they are bright, in part because they reflect all colors, not just one, and they can be made using special white light techniques (*e.g.*, the "rainbow" or "Benton" technique[2]) to give a concentrated and clearly discernable image in various colors.

Not all recording materials used for holography use the volume of the emulsion. Some, *e.g.*, thin photoresist films, harden or soften locally when exposed to intense, blue light. The soft regions are easily dissolved away, leaving a surface relief grating that can diffract light efficiently. The surface



corrugation, and hence the hologram, can be readily mass produced. The photoresist grating can be electroplated with chrome and nickel to make a master for impressing hot transparent plastics. The chromium-nickel master retains its fidelity for many thousands of impressions and is typically used to make continuous rolls of inexpensive holograms.

Embossed pseudo-reflection holograms are the type that are seen on our kids' notebooks and our 1988 OSA membership directory. They have also been suggested for special-purpose playing cards,[3] among other things. The intention is that the value of each card be carried by the holographic image, which would be viewable only within a narrow angular range about the normal to the card face when illuminated from overhead. An observer standing behind the cardplayer would see the card, but would not be able to read its value. Presumably the cardplayer would take notice of people waving penlights from behind trying to reconstruct a displaced holographic image!

In principle, the embossing technique can be applied to any medium that can be impressed with a fine (about one to two thousand lines per millimeter) corrugation. One enterprising soul has actually patented recipes for holographic candies.[4] Sugar solutions are generally pretty sticky, so much of the invention details embossing techniques in gelling and coagulating substances (seaweed and pectin extracts and vegetable gums) in combination with simple sugars or artificial sweeteners that will result in a firm, moisture-resistant embossing. Natural plasticizers and softening agents, such as honey or hydrolyzed cereal solids, are suggested to render the grating less brittle. This is intended to both facilitate removal from the mold and to lessen the chance of breakage during packaging and shipping. The candies do not incorporate a mirrorized surface behind the embossed grating, so a holographic image as viewed in reflection may be somewhat dim, but spectral colors from a simple diffraction grating should be visible.

A kitchen experiment

You can readily replicate holograms in your kitchen. You will need a packet of Knox brand unflavored gelatin, a master grating, and a good point source of light (a beam of sunlight or light from an unfrosted incandescent bulb will do). The grating must maintain its integrity in hot water, so don't use a grating recorded in photographic emulsion. The corrugated surfaces on commercial embossed holograms (credit cards, etc.) are inaccessible, but Edmund Scientific sells sheets of acetate film diffraction gratings that work nicely.

Take a packet of gelatin and mix it in about three or four ounces of boiling water. Stir and then reheat until the mixture is runny. Pour two ounces into a saucer and a drop a one inch square of the grating, relief side down, into the hot gelatin. The film will curl. Cover it with the remaining hot gelatin. Cool the gelatin in the freezer for five or ten minutes, until it has completely gelled. Cut the grating out with a knife and peel away the gelatin from either side. Examine the gelatin in reflection under a point source of light, preferably with something dark, like black construction paper, behind it. Look for glints of colored light, but do it quickly, as the gelatin grating melts within a matter of minutes at room temperature.

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4. U.S. Patent #4,668,523, assigned to E. Begletter of Boston, Mass. on May 26, 1987.

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IEEE surveys members

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—*Susan M. Reiss*

Rainbow holograms

Holograms have become an everyday experience because of two technologies: the "white-light transmission" or "rainbow" hologram that is viewable in white light, and the inexpensive replication of holograms by embossing in plastic. Here, we will examine the first of these as might be found in a typical "silvery blob" hologram from cereal box, T-shirt, or magazine cover, and try to address some of the questions about them that I get asked most often. Find a hologram that has large areas that appear in a single color, as some multicolor holograms are too complex for these experiments.

Although it looks reflective, an embossed hologram can be thought of as a transmission hologram with a mirror behind it ("reflection holograms" are entirely different items). Ordinary laser transmission holograms must be viewed with point-like monochromatic sources of light, such as lasers, or the image becomes blurred. Rainbow holograms are produced with a two-step exposure process—a first hologram is made, then a horizontal strip of that hologram is illuminated to project an image onto a second hologram that is made with a vertically angled reference beam—and can be viewed instead with line sources of white light to produce sharp and colorful images.

When a rainbow hologram is lit with an overhead point source of monochromatic light (such as a diverged laser beam, a filtered mercury arc, or an LED), a real image of the first hologram strip is focused into the space where the viewer's eyes are expected to be. To examine that, illuminate your hologram (held very flat) from above with a monochromatic source at least two meters away. With your head about one meter in front of the hologram, look for a glowing horizontal stripe floating about half a meter in front of the hologram (the location of the stripe can be found by bobbing your head up and down and positioning a finger in space until there is no relative motion between it and the stripe). If you bring your eyes into this glowing stripe, you will suddenly see the entire 3-D image. You can see "look around" as you move from side to side, but no "look under/over" because the image disappears! By the way, any wrinkles in the hologram will deflect light away from your eyes, and that part of the image will look dark. All this may be confused if there are several colors in your hologram. They are not produced by using different colored lasers, but by positioning the strips at different angles during exposure. Thus, you may see several glowing strips at different heights, and each will present a different part of the image to view.

Now look at the hologram with a point-like source of white light, such as a high-intensity light or spotlight, again from overhead and far away. If you have an interference filter available, look through it to see the glowing strip in front of the hologram in whatever color the interference filter transmits. Twist the interference filter so that its transmission color shifts toward the blue, and note that the stripe location moves downward. Without the interferences filter, you should see a spectrum hanging in front of the holograms with red on top and blue on the bottom. You can find its distance by using the finger test again (note that it is inclined). Now, bring your eyes to the spectrum so that they pick up light of a single color, and the hologram image will again appear in 3-D (but without vertical parallax), and in a color determined by the height of your eyes. If you use a slide projector, microscope illuminator, or other focused illuminator, you probably can find the real image of the spectrum on a white card or ground glass held in front of the hologram. The color blur that would result from white-light illumination of a conventional hologram is eliminated because the rainbow hologram diffracts only one color to the eye, making the light source effectively monochromatic.

Illumination of the hologram with a white-light source from below produces a 3-D image that is inside-out! This so-called "pseudoscopic" image is a remarkable feature of holograms, and is a phenomenon of optical phase conjugation (which we don't have room to discuss!). If there were a tag or blip on the right-hand end of the glowing strip when normally viewed, it would be on the left-hand end of the strip during bottom illumination (if you think the image of the end of the slit as formed by an off-axis Fresnel zone plate, and that the two illuminations invoke the positive and negative lens effects respectively, you may be able to make sense of it!). The result is that the right eye sees the image that should have gone to the left eye, and vice versa, so that the depth sense of the image is reversed.

Rainbow holograms can be thought of as focused diffraction gratings in the vertical direction, and off-axis transmission holograms in the horizontal direction. They are harder to make and understand than laser transmission holograms, but their ease of viewing, high brightness, vivid dimensionality, and ease of replication have made them popular commercial items. The sacrifice of information (vertical parallax) has made reduced illumination coherence possible without much degradation of the image; the same principle has also made an early form of holographic video possible, but that is yet another story! OPN

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