The construction and use of simple holograms, and their use in performing experiments, is an excellent way to introduce students to the study of optics.

# HOW TO MAKE HOLOGRAMS USING A LASER POINTER

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As humankind has evolved from the Stone Age through the Age of Electricity, the beginning of the next millennium will usher in the Age of Light. In addition to electronics, we now have photonics. It is the photon from lasers that plays music and video, checks out groceries, sculpts diamonds, performs surgery, and makes holograms.


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The year 1999 will be marked as a milestone in the Age of Light. Diode laser pointers are now available in retail stores, selling for less than $10. Lasers are no longer considered exotic, and have become consumer products that even children can buy and enjoy using.

A surprising feature about the laser pointer, besides its low price, is the high quality of its light. After a warm-up period of a few minutes, the laser produces light with a constant wavelength of between 670 and 635 nm at a power of 2.5 to 4 mW (Class IIIa). The coherence length of more than 1m makes it superior to the helium-neon laser for many applications, among them the making of holograms.

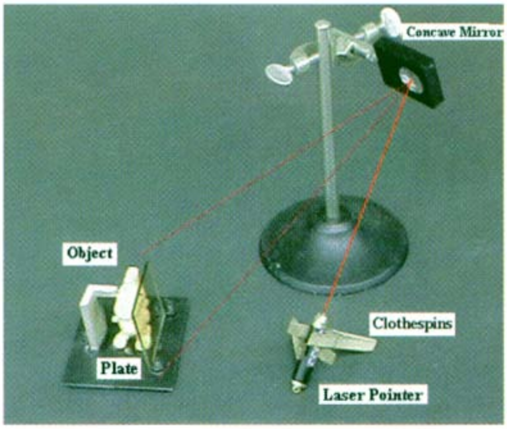
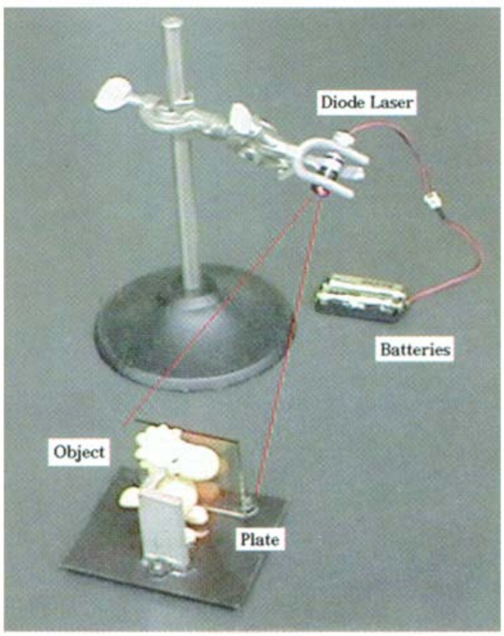



**Figure 1.** (above) Setup for making a reflection hologram using an un-modified laser pointer. The two clothespins form a tripod and turn on the laser. The concave mirror spread the light.

**Figure 2.** (below) The diode laser without a collimating lens emits a spreading beam. Thus no additional optics in needed in making a hologram.




Teaching students of all ages to make holograms for artistic and technological applications, besides being a highly creative endeavor, teaches all the basic principles of optics. The theory of holo-graphy relates directly to the Nobel Prize concepts of Lippmann (1908), Bragg and Bragg (1915), and Gabor (1971).

Like the laser, holograms are becoming ubiquitous. They are imprinted onto candy wrappers, gift-wrapping paper, credit cards, and security devices. Holography is also taught in art schools and used in trade shows and commercial displays. Even more important, holographic optical elements (HOEs) are used for scanning, heads up displays (HUDs) in aircraft, computer memories, and an endless list of other technological applications.

Lasers and holograms are as essential to future photonic devices as diodes and transistors were for electronic devices. Additionally, making holograms is not only enjoyable, it is also the best way to begin learning the fundamentals of photonics.

The goals of this article are to show how to

- Use the laser pointer without any modification to make a Denisyuk hologram viewable with a point source of incandescent light
- Make a superior hologram of the same type, without the need of a beam-spreader by removing the collimating lens
- Use the naturally diverging beam, with a highly eccentric elliptical profile, to make panoramic transmission and reflection holograms viewable with the same laser light, and
- Construct an elegant system that performs real-time holographic interferometry on phase objects.

Figure 1 shows a method of making a white light viewable reflection hologram using the laser pointer with minimum additional equipment. The laser forms one leg of a tripod. The other two legs are clothespins. Then a front-surfaced concave mirror diffuses the collimated beam.[1] Finally, the beam illuminates a solid object not much larger than the 6.35 cm × 6.35 cm holographic plates to be used.

After combining these elements, set the entire structure on a solid surface, with enough ordinary light allowed to provide minimal visibility after dark adaptation, then direct the spreading laser beam at the object. Adjust the distances and orientations of all elements until the object is illuminated as evenly as possible. Now block the beam near the laser with a shutter, such as a piece of cardboard, to prevent the light from reaching the object. Then place a holographic plate (Slavich PFG-01M)[1] in contact with the object, with the emulsion (sticky) side facing it. After a setting time of a few seconds, expose the plate for 5 seconds by lifting and lowering the shutter. If there is air movement or too much ambient light, a box painted black on the inside should be placed over the entire structure.

Next, develop the plate by using a chemical kit called JD-3,[1, 2] and by following the instructions that came with it. Then develop the plate in a white tray until opaque (1–2 min); rinse briefly in distilled water; bleach with copper sulfate (part of JD-3) until completely clear; rinse again until all yellow color is gone; develop again in vitamin C with light on (sunlight is best, but any bright light will do) until the hologram turns brown; then rinse and allow the hologram to dry. A hand-held hair dryer may be used to shorten the drying time. The thoroughly dried hologram can then be viewed using a pen flashlight[2] or any point incandescent source. This particular chemical process minimizes emulsion shrinkage, and allows the red image to be viewed with the spreading laser light as well, with increased image resolution. (See Reference 3 for a detailed discussion of the chemical process.)

However, because the collimating lens has two surfaces, their reflections form interference patterns on the spread out beam. In addition, dirt collected on the lens and concave mirror causes diffraction patterns. Thus, the above hologram is expected to have a mottled pattern across its surface.

Remove the built-in collimating lens from the pointer, and the remaining unit will emit light that spreads out in an elliptical cone. The beam is as completely clean as if it had been spatially filtered, and the exposure over the holographic plate is more even. The concave mirror is no longer needed. Holograms made with this laser are free of mottled patterns. Furthermore, the small and expensive batteries can be removed and the bare laser unit can be connected to two 1.5 volt, size D batteries in series. Then, even applying only 3.0 volts, the laser still yields over 2.5 mW and its life expectancy is greatly extended. Such a minimal laser is commercially available.[4]

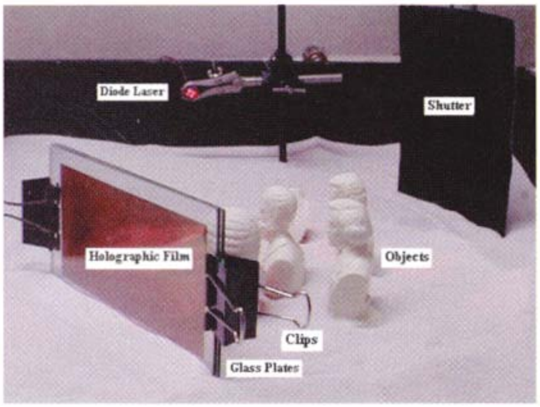
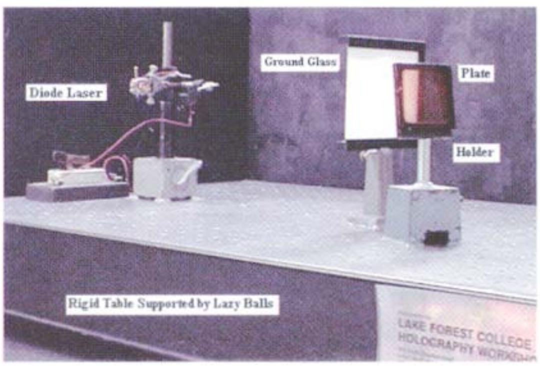



**Figure 3.** The highly eccentric elliptical beam is used to make a transmission hologram with a panoramic scene.

**Figure 4.** A real-time phase holographic interferometer is made by adding a ground glass and a special plateholder.




After obtaining such a laser, erect it at the previous location of the concave mirror (see Fig. 1) and rotate it until the elliptical beam has its long axis in the vertical position. Then, record the same type of hologram with an exposure time of about 10 seconds. This new hologram is superior to the ones shown in Figure 2 because the direct laser light that served as reference beam has no interference or diffraction patterns. By taking advantage of its highly eccentric elliptical beam, transmission holograms with extraordinary wide angles of view can be made.

Figure 3 shows the configuration used for making a deep scene panoramic transmission hologram. Construct a sandbox using clean silica supported by eight lazy balls.[1] These balls have zero coefficient of restitution at 23°C and provide a rigid base that minimizes vibration and wobbling. Place the laser at one corner with its beam spreading across the sand.

Next, place several objects across one side of the spread-out beam and a long horizontal strip of holographic film on the other side as shown. Note that the polarization of the laser light is horizontal. The film should be rotated so that the incident angle is about 57°, near the Brewster angle (the angle in which all incident light is transmitted) thus avoiding the thin-film interference effects caused by the internal reflections.

It is extremely important to keep the film from any movement during exposure. Sandwich the film between two large glass plates and use strong paper clamps to hold it in place. Then, stick the sandwich into the sand as shown, and wait for at least five minutes for the trapped air to escape before exposure. The exposure generally takes 30 seconds.

Develop the hologram the same way as before and the virtual image can then be viewed by light from the same laser under the same configuration as during the exposure. The real image of the hologram can be projected onto a white screen if a collimated laser beam is directed at the hologram in a backward direction. The screen should be located at the approximate position of the objects.

The usefulness of these processes can be extended by the use of holographic interferometry. For schools that have long-term courses or programs in the study of optics and photonics, it is worthwhile to invest in high quality optical tables and components because many additional experiments can be performed with higher quality equipment. Figure 4 shows a simple but extremely useful system for performing real-time holographic interferometry on phase objects.[5] It consists of a rigid table supported by lazy balls, diode laser, ground glass, and an Abramson plate holder.[6]

The Abramson plate holder is a rigid metal frame made to support the holographic plate, allow it to be removed for development, and then allow it to be replaced in a position precisely the same as the position it occupied during exposure. The plate holder has three long pins (two at bottom and one on the side) that define two edges, and three short round points that define the plane of the plate. It is tilted forward slightly. By placing and tapping the plate until all six points are in contact, gravity helps to hold it in a unique position.

To set up the interferometer, rotate the diode laser until its beam is spread out horizontally. Part of the beam will illuminate the ground glass and another part will serve as a reference beam. Thus, a transmission hologram has been made in which the ground glass is the object.

After the hologram is processed and precisely relocated at the plate holder, a virtual image of the ground glass can be seen through the illuminated hologram. At the same time, the actual illuminated ground glass can also be seen. Assuming there is no displacement of any components, and that there is no disturbance in the optical path due to air currents, the light forming the virtual image interferes with light from the ground glass at the zeroth order and no interference fringe can be seen.

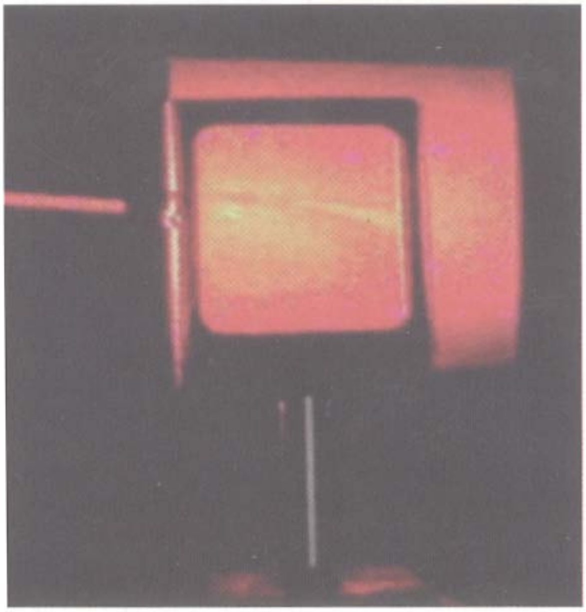


**Figure 5.** Photograph of a jet of air made visible by the real-time phase holographic interferometer.

If a phase object such as an air stream or heat wave is now introduced in either the object or reference beam paths, the differences can now be visually observed as black and red fringes. Figure 5 shows a jet of air from a hose introduced from the left side of the ground glass. Thus, the system serves as an inspection instrument useful for studying a host of technical problems involving phase information.[7]

Transparent objects, such as a beaker of water, can be placed in the object beam path before the ground glass during recording. Any subsequent phase changes in the object, such as adding hot water, will render the changes visible.

Many other projects can be performed with a minimum of additional equipment. For example, just by adding a front surface mirror, the following experiments are possible

- High dispersion diffraction grating: deflect part of the beam with the mirror to interfere with the reference beam at the recording plate.
- Multi-channel hologram: after exposing a transmission hologram, rotate the recording plate (or film) 180° (with the normal to the plate plane as axis), replace the object, and expose again. Each exposure should be one-half of the full time. After processing, the images of each object can be seen independently. This demonstrates the potential of the hologram as an information storage medium.
- Double exposure interferometry: expose one-half the time, stress, or heat the object slightly, and expose it for the remaining time. The two recorded images will interfere with each other and show fringes that precisely denote the vector displacement of the object surface.

These experiments have clearly shown that the diode laser has made it possible to make high quality holograms safely, economically, and efficiently. And, because holography is a subject rich in educational content, members of the optics profession should study it not only for their own pleasure, but they should also teach it in their classrooms and to their children at home. Such activities will help to broaden knowledge of the field of optics for the public and perhaps even help to recruit a new generation of students into optics and photonics programs. (For further information, please see References 8, 9, and 10.)

## References


1. All Slavich and Agfa silver halide recording film and plates, processing kits, beam-spreader, "lazy balls," educational holograms, video, and book instructions are available from Integraf. E-mail: integraf@aol.com; fax: 847-615-0835. Web site: http://members.aol.com/integraf.
2. Rayovac penlight (V2AAA-B), $1.99 (including batteries), K-Mart.
3. Hans I. Bjelkhagen, *Silver-Halide Recording Materials for Holography and Their Processing,* Second Edition ( Springer-Verlag, New York, NY), 1995. ISBN 3-540-58619-9. Available from Integraf.
4. The laser used is Item # VM65003 from Midwest Laser Products; 815/464-0085; fax: 815/464-0767; http://www.midwest-laser.com.
5. T.H. Jeong and L.M. Spoto, "Real-time High Speed Holographic Interferometric Study of a Fuel Injection System," Proc. SPIE **3358** (Bellingham, WA, 1997) 305–311.
6. Private communication with Nils Abramson, Professor Emeritus of the Royal Institute of Technology, Stockholm, Sweden.
7. Charles Vest, *Holographic Interferometry* (Wiley Interscience, 1979) ISBN 0-471-90683-2.
8. V. Sainov, *et al.*, "A Portable Device for In-situ Recording of Reflection Holograms with Diode Lasers," Proc. SPIE **3358** (Bellingham, WA, 1997) 397–405.
9. G.J. Koch and M. Petros, "A simple overhead denisyuk configuration for making reflection holograms with a diode laser," Am. J. Phys. **66** (10), 933–934 (1998).
10. Communication with Frank DeFreitas, director@holoworld.com



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