Daguerreotype holography

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Abstract

The daguerreotype process, invented in the late 1830s, was the first photographic technique to be commercialised. Images are recorded on polished silver plates that have been sensitised with iodine or bromine vapour, exposed with short-wavelength light, and developed with mercury vapour. Exposed areas become coated with fine diffusely-scattering particles, and under the right conditions of illumination are seen as bright against the dark background of the specularly-reflecting polished silver surface. Daguerreotypes are well known for their ability to record very finely detailed images, but few quantitative studies of their spatial resolution exist.

An investigation was undertaken to determine whether it is feasible to use the daguerreotype process to record holograms. Two-beam interference fringe patterns with periods as small as 0.8 μm were recorded on daguerreotype plates in argon laser light at 488 and 458 nm, and diffraction efficiencies of up to 3% were obtained with exposures in the range of 1–10 J/cm^2. A rainbow hologram was successfully recorded on daguerreotype with a 5 min exposure of 0.7 J/cm^2 in 458 nm light.

The technique is of interest because it combines one of the oldest image recording techniques with one of the newest. Practical applications also exist in the fields of art, decoration and silversmithing.

1. Introduction: The daguerre process

In 1839, Louis Daguerre published a method of recording images on metal plates that was to become the first photographic process to be commercialised. The technique relies on the optical and chemical characteristics of the compounds of silver with halogens, but is quite different to the later-developed silver halide process. A brief description of the daguerre process follows: much more detail is available elsewhere [1].

A flat, smooth copper plate is electroplated with a thin layer of silver metal, which is then polished to a high-quality mirror surface, free of scratches, so that under illumination the surface appears dark at angles away from the specular reflection angle. The plate is then sensitised (in darkness) by successive contact with iodine and bromine vapour, forming a thin layer of silver halogen compound on its surface. The colour of the film, produced by thin-film interference and observed under subdued lighting, is monitored to determine when the desired thickness (a few hundred nanometres) has been reached. The colour changes through the interference colour cycle, beginning with pale yellow, orange, red, violet, blue, green, then back to yellow and so on, the colours in the second cycle being more saturated. Generally, colours in the second cycle are favoured. There are various recipes and recommendations for proportions of iodine to bromine, sensitising times, and best colours, depending on the desired outcomes. This part of the processing relies heavily on the skill and experience of the practitioner.

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The plate is then exposed to the image to be recorded, in a suitable camera. The medium is most sensitive to the short-wavelength end of the visible spectrum. Exposures under full daylight illumination typically take a few minutes at a wide aperture. During exposure, photoreduction of the silver halogen film to fine metallic silver particles occurs.

To enhance the image, the plate is developed. Traditionally, this is done by bringing the plate into contact with mercury vapour for several minutes. The mercury amalgamates with the silver to form fine scattering particles on the surface of the plate. Alternative methods of development exist, notably the Becquerel technique in which silver crystal growth occurs through further, prolonged exposure of the plate to uniform illumination with red light.

The plate is then washed in photographic fixing solution to remove remaining silver halide, rinsed in distilled water and dried. Finally, it may be protected by chemically depositing a gold film over the exposed surface, which also enhances its tonality.

The image is seen by illuminating the plate obliquely and viewing it at normal incidence. The finely divided scattering particles in areas that have been exposed to light are seen as bright against the dark background of the specularly-reflecting polished silver surface. A positive image is therefore formed. However, it is also possible to see the image in reversed (negative) contrast if a viewing direction close to the specular reflection is chosen.

The daguerreotype was in vogue for only about 15 years before it was overtaken in popularity by more convenient and less expensive photographic techniques. The many variables in the sensitisation, exposure and development procedures make daguerreotypy quite an art, and even the

Table 1
Details of processing of daguerreotype plates

Plate	Sensitisation	Exposure λ (nm)	Fringe spacing d
A	Iodine, 3 min to 2nd yellow	488 and 458	Coarse
B	Iodine, 2 min to 1st gold; Bromine, 2 min;Iodine, 30 s	488	Moderate, 50 μm
C	Iodine, 6.5 min to 2nd gold; Bromine, 2 min; Iodine, 20 s	488	Fine, 2.4 μm
D	Iodine, 5.5 min to 2nd gold; Bromine, 1 min;Iodine, 54 s	488	Very fine, 0.85 μm

most experienced practitioners still find that results are not always predictable. However, the fine quality and high resolution of the best daguerreotypes are most impressive, and today daguerreotypy continues to be practised and studied by artists, hobbyists and enthusiasts [2].

2. Application to holography

In order to be able to record holograms, a medium must respond to light exposure by changes in its amplitude or phase transmission or reflection characteristics, and it must have high spatial resolution. The daguerreotype is renowned for its ability to record fine detail, although little quantitative information is available on its limit of resolution. The daguerreotype plate would be expected to function as a plane amplitude hologram: the exposed areas (bright interference fringes) scatter and attenuate the illuminating beam in much the same way as the absorbing silver particles do in a conventional silver halide emulsion, whereas the unexposed, smooth silver surface reflects the incident wavefront unchanged.

The most suitable type of holographic recording for the medium is the rainbow hologram, for several reasons. The rainbow hologram is designed for viewing under white-light conditions, and does not require a laser for display. It works with plane hologram recording media, as opposed to volume recording. It is made in a two-step process: recording a master hologram, and projecting the master image onto the final plate. The master can be made with conventional holographic recording materials, and if it is efficient it can generate high irradiance levels in the projected image, minimising exposure time. The angle between the object and reference beams can be made small to increase fringe spacing and reduce the demands on the recording resolution. Finally, the rainbow hologram image is very bright because of the concentration of diffracted light into a “viewing slit” in the vicinity of the viewer’s eyes, hence giving a reasonable result even if the diffraction efficiency is low.

The final rainbow image would be seen in reflected light, although technically it is not a reflection hologram: the silver surface supplies the reflection. In this respect it would be similar to the embossed foil rainbow holograms found on credit cards and book covers.

3. Sensitivity and resolution measurements

The sensitivity, resolution and optimum exposure of the daguerreotype plates were investigated by creating test diffraction gratings and then measuring their diffraction efficiencies. This was done for a range of plate preparation and development processes, exposure times, and interference fringe spacings.

Optical configurations for creating two-beam interference patterns were set up as described below on a vibrationally-isolated optical table in a temperature-controlled laboratory to minimise fringe motion due to mechanical movements, vibrations and air currents. The 488 nm blue wavelength and 458 nm violet wavelength of an argon-ion laser were used. Since the laser power could be concentrated onto a small area of the plate, about 20 mm in diameter, the irradiance could be made quite high, and exposure times could be relatively short. Irradiances at the plate were measured with a luxmeter, and the readings were converted to watts per square centimetre using the conversion factor between lumens and watts (the luminous efficacy) applying at the particular wavelength in use. At 488 nm, the luminous efficacy is 130 lm/W, and at 458 nm it is 38 lm/W. Several exposures of various times were made on different areas of the one plate so that plate preparation and processing conditions were the same for each.

After each plate was exposed, developed and fixed, the relative efficiencies of fringe recording were compared by measuring the diffraction efficiency of each exposed patch. This was done by directing the beam from a small laser diode (wavelength about 680 nm) onto each patch in turn, and measuring the ratio of the maximum power in the diffracted beam to that in the incident beam, using a silicon photodiode detector connected to a digital ammeter.

Four sets of measurements were made, on four daguerreotype plates, referred to here as A, B, C and D. Plate preparation and exposure details are summarised in Table 1.

Due to the long exposure times, sensitising was restricted to the iodine/bromine method for plates B to D, as it was known from previous research that this combination had the faster speed. The mercury vapour technique was used throughout for development.

Table 2
Details of exposures and diffraction efficiencies for Plate A

Wavelength of exposure (nm)	Power/area (mW/cm^2)	Exposure time (s)	Exposure (J/cm^2)	Diffraction Efficiency (%)
458	0.90	30	0.027	0.15
458	0.90	240	0.22	0.10
488	5.4	30	0.16	0.49
488	5.4	240	1.3	not measurable

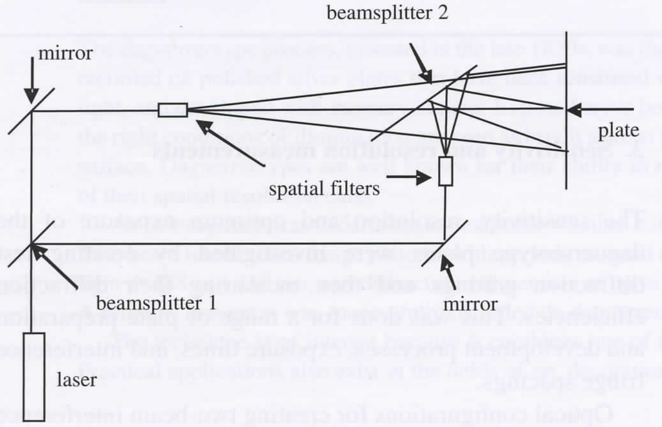

Fig. 1. Recording configuration for Plate A.

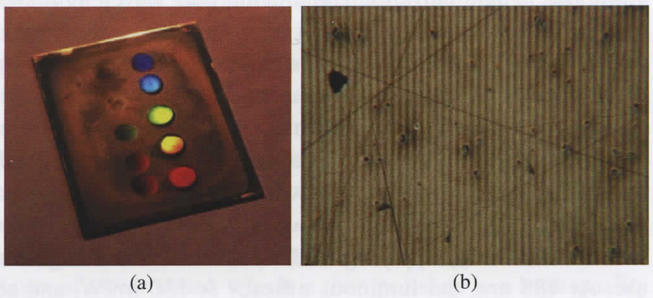

Fig. 2. (a) Plate C illuminated by tungsten-filament desklamp. The exposed patches show diffracted spectral colours depending on the angles of illumination and viewing. Exposure time increases anticlockwise around the plate from 0.1 s at top left to 128 s at top right. (b) Micrograph of interference fringes recorded on Plate C, 128 s exposure. Spacing of fringes is about 2.4 µm.

3.1. Plate A

A fringe pattern with spacing that varied across the exposed area was created with the optical configuration shown in Fig. 1. The laser beam was split into two with beamsplitter 1, redirected with mirrors and passed through spatial filters. The diverging beams were then recombined with beamsplitter 2 and directed onto the plate. Since the distances of the spatial filters from the plate were different for the two beams, there was a range of angles between rays on the plate, from parallel to each other at one side to a fairly large angle on the other side.

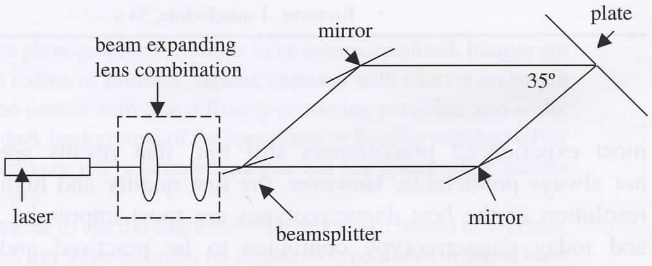

Fig. 3. Recording configuration for Plate D.

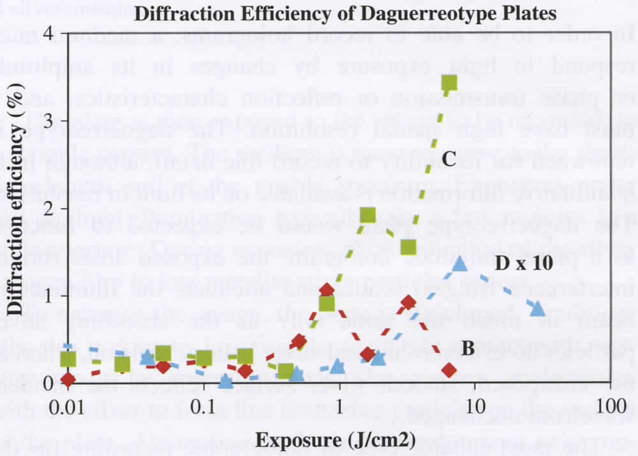

Fig. 4. Diffraction efficiencies at 488 nm, measured for Plates B, C and D. The scale for Plate D has been magnified by 10.

The two beams were adjusted so that the power per unit area delivered to the plate was approximately the same for each, and the total was measured with the luxmeter. Tests were done with two wavelengths of the argon laser, 458 nm and 488 nm, and exposures were made at 30 and 4 min for each line. The four combinations were exposed on different areas of the same plate.

Table 2 shows details of the exposures and measurements of the diffraction efficiency. The best result was with the 488 nm line at 30 s, with a plate exposure of 0.16 J/cm^2. The diffracted beam with the long exposure at 488 nm was too faint to be measured. It is probable that this was because of fringe drift during exposure, rather than overexposure. A similar reduction in efficiency may have occurred with the long exposure in the 458 nm line. Under the microscope, interference fringes could be seen on the daguerreotype plate in the first three cases.

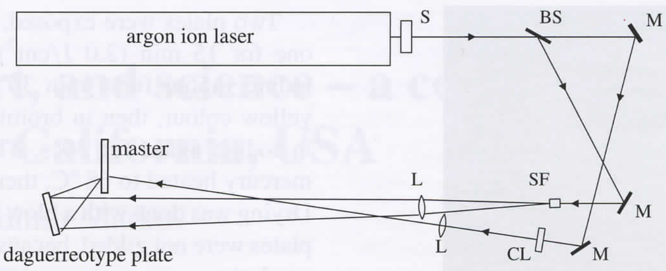

Fig. 5. Setup for transfer of holographic image to daguerreotype: S–shutter; BS–beamsplitter; M–mirror; SF–spatial filter; CL–cylindrical lens; L–lens.

3.2. Plate B

Because of the higher power available in the 488 nm laser line, and because promising results were obtained with this line on Plate A, further tests were done using this wavelength only. The optical configuration for exposure was similar to Fig. 1, but the spatial filters were placed at a common distance far from the plate, so that both beams were only slightly divergent. The first beam was incident perpendicularly on the plate (angle of incidence $\theta_1 = 0°$), and the second at a small angle ($\theta_2 \approx 0.5°$), giving a coarse fringe separation of $d \approx 50$ μm. The laser beam power was increased to give a total power per unit area at the plate of 50 mW/cm^2. Ten exposures were made on the one plate, with exposure times varying from 0.2 s to 128 s in a doubling sequence. Measurements of diffraction efficiency were done in the same way as for Plate A, and are summarised in the plots in Fig. 4.

3.3. Plate C

This plate was exposed under similar conditions to Plate B, except that the angle of the second beam was increased to $\theta_2 \approx 12°$, giving a finer fringe spacing of $d \approx 2.4$ μm. This plate showed strong diffracted colours under white light illumination, as shown in Fig. 2(a), and good contrast interference fringes were seen under the microscope, as in Fig. 2(b). Under higher magnification, individual silver grains with sizes in the sub-micron region could be seen. Diffraction efficiencies are again shown in Fig. 4.

3.4. Plate D

The fourth plate was exposed with a very fine fringe separation, more typical of the conditions for recording a hologram. For this, a slightly different optical arrangement was used, as shown in Fig. 3. A lens combination was used to expand the laser beam into an almost collimated beam, which was then split, and recombined at the plate with $\theta_1 = 0°$, $\theta_2 = 35°$, giving a fringe spacing of $d = 0.85$ μm. The power per unit area was close to 100 mW/cm^2. Eight exposures ranging from 0.1 s to 300 s were carried out. Diffraction efficiencies also appear in Fig. 4, but the scale has been multiplied by 10 for clarity.

3.5. Discussion

The plots of diffraction efficiency in Fig. 4 show considerable scatter in the results, but there is a general trend towards best efficiency for exposures over 1 J/cm^2. Some variability is expected from plate to plate due to differences in sensitisation parameters, and the general unpredictability inherent in daguerreotype processing. Variations on a single plate, however, are more probably due to instabilities and drifts in the optical recording setup. Response at 0.85 μm fringe spacing (Plate D) is an order of magnitude below that at 2.4 μm. It is uncertain whether this is due to the limit of resolution of the daguerreotype being approached, or because the plate processing was less than optimum.

The best diffraction efficiency in the tests was 3.5%, obtained at 488 nm with a fringe spacing of 2.4 μm and an exposure of 6.5 J/cm^2 (50 mW/cm^2 for 128 s). This efficiency is very good, since the theoretical maximum efficiency to be expected from a plane amplitude hologram under best conditions is around 6%. Acceptable efficiencies of 1.5–2% were obtained with exposures around 1 J/cm^2. The daguerreotype plate is roughly 5000 times less sensitive than a typical silver halide holographic plate at this wavelength.

4. Production of rainbow holographic daguerreotype

First attempts to produce a rainbow holographic daguerreotype were not successful. A master hologram was recorded in 488 nm laser light on an Agfa-Gevaert Holotest 8E56 silver halide plate. The reconstructed image was projected onto the daguerreotype plate in the normal rainbow recording configuration. With the maximum laser beam power available at 488 nm, the best irradiance that could be achieved on the plate was 420 μW/cm^2 (550 lux), requiring an exposure time of 40 min to give 1 J/cm^2. Although it is unreasonable to expect absolute fringe stability over this time, a result might still be possible if fringes drift only a small distance about some average position, producing a holographic image with reduced efficiency in a similar way as in a time-average hologram of a vibrating object.

Several exposures were made, with differing beam ratios and plate sensitisations. Almost all of these attempts were unsuccessful in producing holographic images, although a general fogging of the plates was noticeable, showing that

Fig. 6. Rainbow hologram daguerreotype, illuminated with tungsten filament lamp.

they had been exposed. The best result was obtained with a plate sensitised to the second stage gold colour with iodine for 2 min, followed by 1 min bromine, and 20 s iodine. After exposure, the plate was developed with mercury. A faint, noisy image was visible, demonstrating that holographic recording was possible.

More recently, a new argon-ion laser with higher power capability was acquired. It was expected that the daguerreotype plates should be more sensitive to the 458 nm line, and this wavelength was used to record a new master hologram on a Slavich PFG-03C plate. The subject was a small ceramic figure of a cat holding a glass bead. A transmission master hologram with good diffraction efficiency was produced.

The image was transferred to the daguerreotype plate with the configuration sketched in Fig. 5. A cylindrical lens (a 17 mm diameter test tube filled with water) generated a strip of light across the master hologram, projecting an image that straddled the plane of the 60 mm × 90 mm daguerreotype plate. Lenses were used to reduce the divergence of both beams, hence reducing image distortion on reversal of beam directions when the final hologram is viewed. Master and final hologram beams were crossed as shown to reduce the angle between object and reference beams on the daguerreotype to an average of around 15°. This produced fringe spacings between 1 and 4 μm on the plate. Total laser beam power was 330 mW at 458 nm. The reference:object beam ratio was roughly 10:1 on average, although there were some bright highlights on the projected image. Total plate irradiance was about 2.3 mW/cm^2.

Two plates were exposed, one for 5 min (0.7 J/cm^2) and one for 15 min (2.0 J/cm^2). They had been sensitised in iodine vapour for 4 min 30 s at 22 °C to the second cycle yellow colour, then in bromine vapour for 30 s, and finally in iodine again for 30 s. The plates were developed over mercury heated to 68 °C, then rinsed, fixed and rinsed again. Drying was done with a blow heater on a low heat setting. The plates were not gilded, because of fear that it might reduce the resolution.

A very pleasing result was obtained from the 5 min exposure. Fig. 6 is a photograph of the plate, illuminated from above with a small tungsten filament lamp. The holographic image is reasonably bright and shows good uniformity and low noise. There is no apparent diminution of efficiency towards the bottom edge of the plate where fringe spacing is smallest, at around 1 μm. The 15 min exposure was much less clear, showing only a faint image in patches. Again, plate preparation and developing variability may have been a factor in its poorer performance, but it is encouraging that good results were obtained with the lower exposure. This represents, as far as we know, the world's first example of a holographic daguerreotype.

5. Conclusion

It has been shown that the daguerreotype process has the required resolution for the production of holographic images. Diffraction efficiencies which are over half the theoretical maximum for plane amplitude holograms have been obtained for a fringe spacing of 2.4 μm at 488 nm and an exposure of 6.5 J/cm^2. A good rainbow hologram has been recorded at 458 nm with an exposure of 0.7 J/cm^2. The quality of the image indicates that recording resolution is still good at a fringe spacing of 1 μm. Because of the low sensitivity of the medium, exposure times are long, but with a few hundred milliwatts of laser power at 458 nm exposures can be reduced to five minutes or less. Further experimentation is needed to establish best sensitisation and development procedures, and whether gilding is detrimental.

The possibility of recording holograms on daguerreotypes opens up new avenues of expression and exploration in the realms of art, decorative craft, jewellery and silversmithing.

Acknowledgements

The idea for this project came about through a suggestion from professional daguerreian photographer Charlie Schreiner whose advice and encouragement are greatly appreciated.

References

[1] M. Susan Barger, William B. White, *The Daguerreotype: Nineteenth Century Technology and Modern Science*, Johns Hopkins University Press, 2000.

[2] See the website of the Daguerreian Society http://www.daguerre.org.