45° RGB SBR HOE for the evaluation of the performance of holographic recording materials

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ABSTRACT

A novel holographic recording scheme that does Yuri Denisyuk proud is utilized to gather numbers from a couple of panchromatic silver halide recording materials at a trio of wavelengths. Results of diffraction efficiency and spectral bandwidth are given.

Keywords: single beam reflection hologram, holographic optical elements, Ultimate holographic plates, Sphere-S holographic plates

1. INTRODUCTION

1.1 Purpose and scope

It was deemed necessary to measure the diffraction efficiency of silver halide recording materials in the reflection hologram mode for a consulting project, plus just for general knowledge. A simple solution set up was devised, and its implementation is detailed. Hopefully other holographers can use this set up and gather their own information for their favorite recording materials.

There was no need to expose the large plates required for the project to gather the data, the smallest packaged units, 62 mm squares (2 ½”) would suffice. A Single Beam Reflection Hologram of a Mirror would be sufficient to simulate the final project’s two interfering beams.

2. METHODOLOGY

2.1 Ray-tracing sketch

In this sketch of the set up, the expanded and collimated laser beam is coming from the left, as is usual in optical schematics.

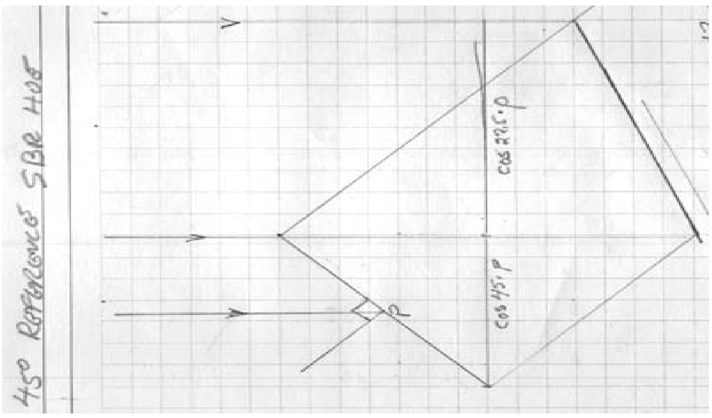


Figure 1: Conceptual sketch of the set up.

The lowermost depicted ray is incident on the center of the holoplate at the requisite reference angle of 45°. There is a ray above it which just misses the holoplate, but is reflected by a front surface mirror to arrive along the normal to the bottommost portion of the plate. Positioning the mirror this far back eliminates any shadows cast by the recording material which would attenuate this beam and add its scatter to this beam, possibly making it not a true point source but something on the diffusely scattering side, especially at the bluer wavelengths. The mirror's normal is tilted half the angle of incidence of the holographic plate, 22.5° in this case, to provide the normal incidence from the back.

2.2 On the table

Here is the physically implemented set up:

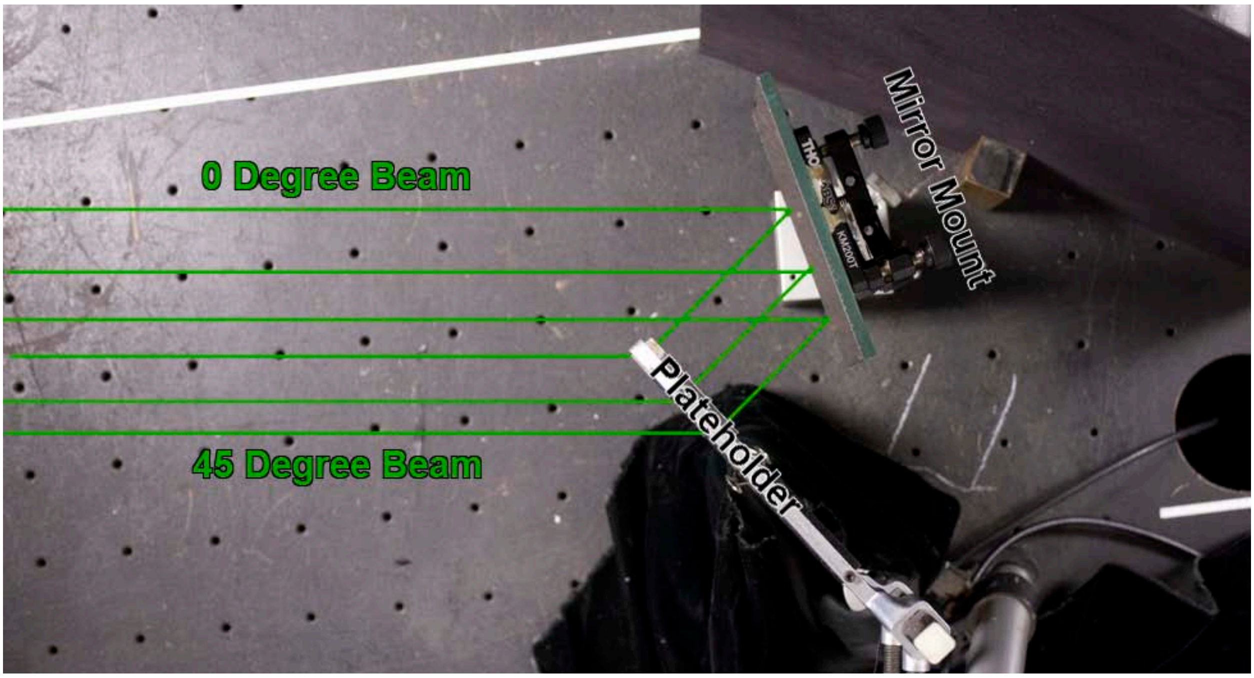


Figure 2: 45° reference beam, 0° incidence object beam, from a single beam.

2.3 Beam balance ratio

Although this is a single beam set up, the beam balance ratio can still be controlled. Laser beams' profiles are not even but vary along the diameter in the well-known Gaussian distribution. This beam profile was translated across the holographic plate and "object" mirror by translating a long focal length negative lens before the spatial filter. And before inserting its pinhole.

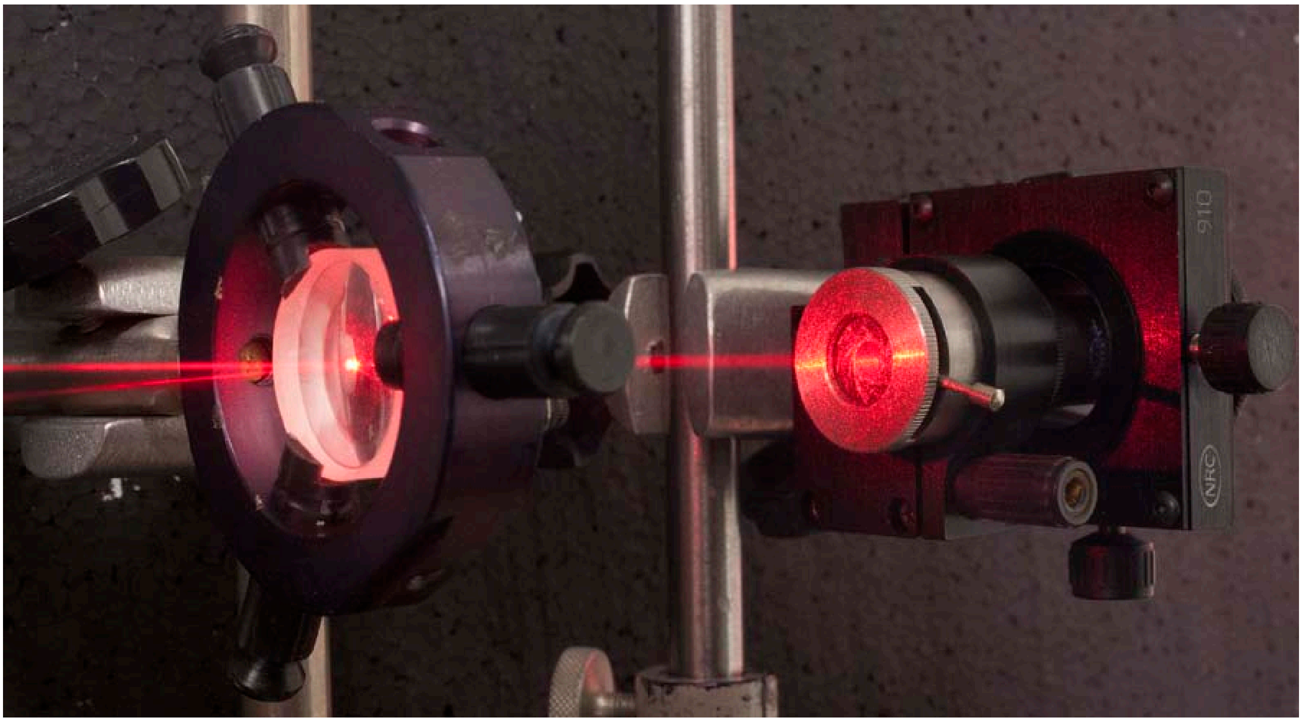


Figure 3. Translating the pre-spreading lens will shift the beam profile.

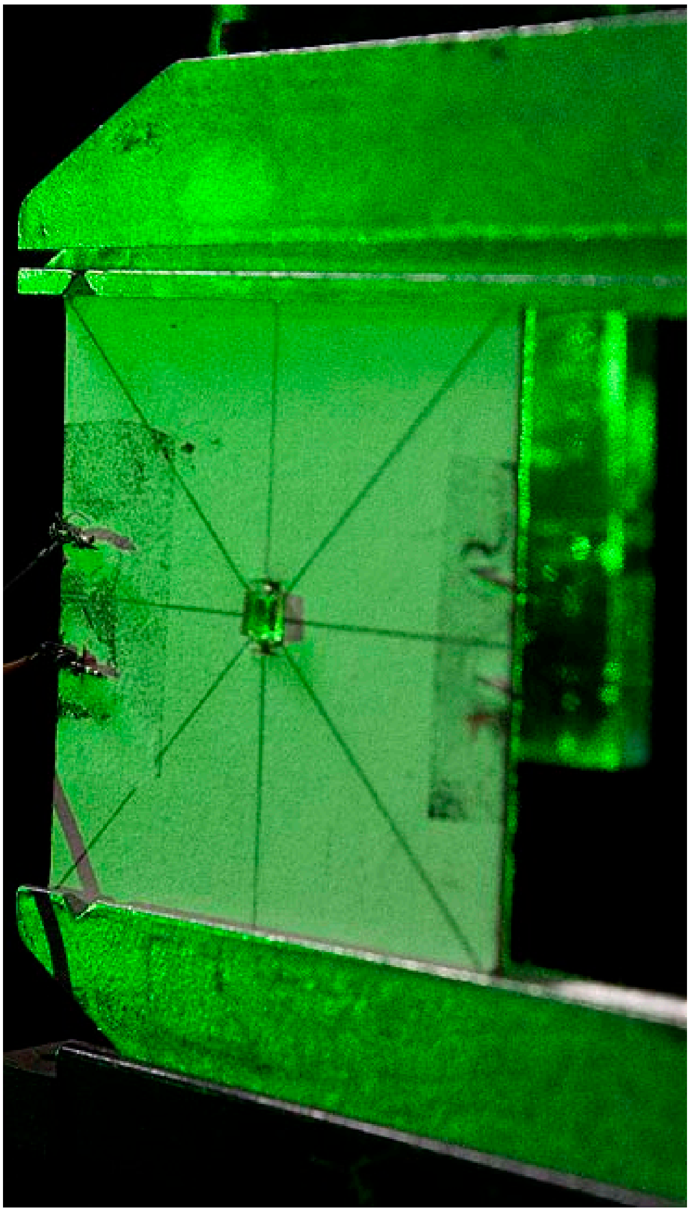


Figure 4: A simple silicon detector was positioned in the center of a piece of cardboard of the holoplate dimensions, inserted into the plateholder, and measured the radiant flux on first one side and then the other.

The laser beam's profile was shifted with the pre-spreading lens until the detector read the same amount of light on both sides of the plate. The brighter center of the Gaussian profile was illuminating the 45° incidence side, due to incident angle attenuation and reflection, and the beam along the normal which was not so affected used the weaker outer portion of the beam. The beam was about 25 cm in diameter, so this trick could be pulled off. There were gradients of flux out in the edges, but a 1:1 ratio was attained in the center of the holoplate.

The polarization vector of the beam was rotated by a half-wave plate so that there was the minimum amount of reflection from the reference beam from the glass of the holographic plate.

2.4 Exposures

Samples of holographic recording materials were positioned in the plateholder and exposed at a variety of energy levels, generally bracketing around the manufacturer's suggested exposure dose and plus and minus a photographic stop by half stops. For example, if the manufacturer claimed sensitivity of 600 microJoules per square centimeter, then the exposure series would go 300, 420, 600, 840, and 1200 microJoules per square centimeter, for full stop less, half stop less, recommended, half stop more, full stop more.

Then they were processed in what was deemed the best soups for the job. Not only should the processing deliver bright results, but there should be no distortion like shrinkage or expansion of the layer to change the replay color. This parameter was checked with a spectrometer. The processing for both of the materials tested gave the desired results.

2.5 Measurements

To characterize diffraction efficiency, Iris Diaphragms were positioned to change the recording set up into an in situ interrogation set up.

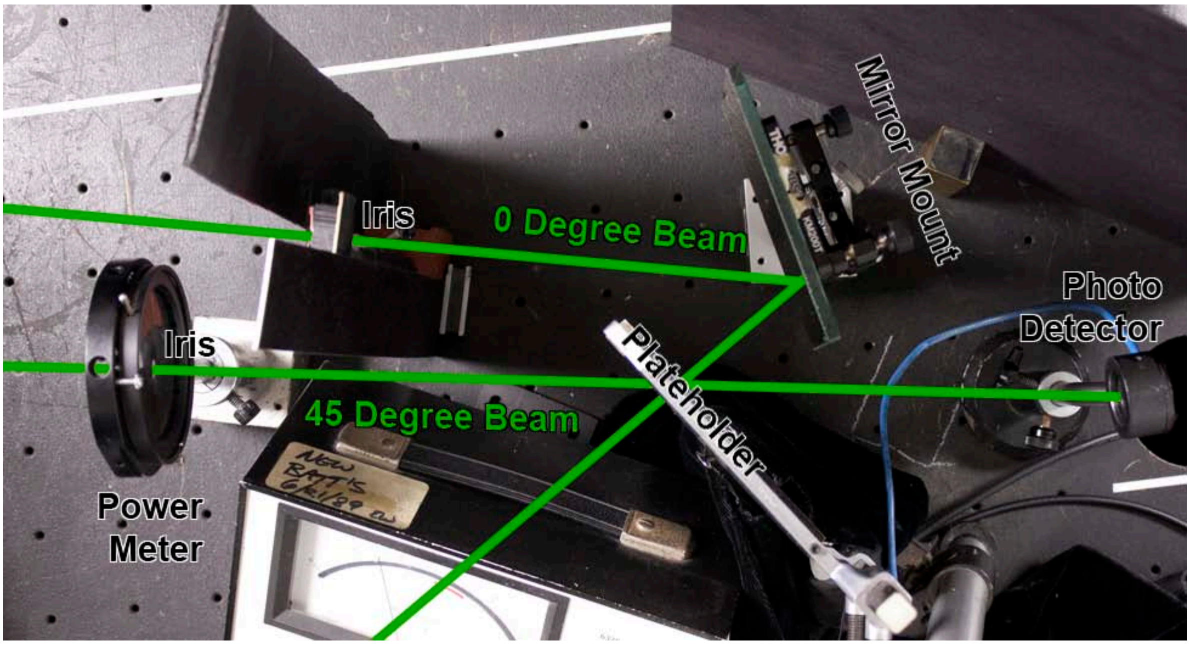


Figure 5: Iris diaphragms were positioned in the parts of the large spread beam corresponding to 45° direct incidence and 0° incidence by way of the mirror.

Iris diaphragms were positioned in the parts of the large spread beam corresponding to 45° direct incidence and 0° incidence by way of the mirror. The irises were translated in the beam so that their projections were centered on a piece of groundglass, with alignment guides, the size of the sample plates.

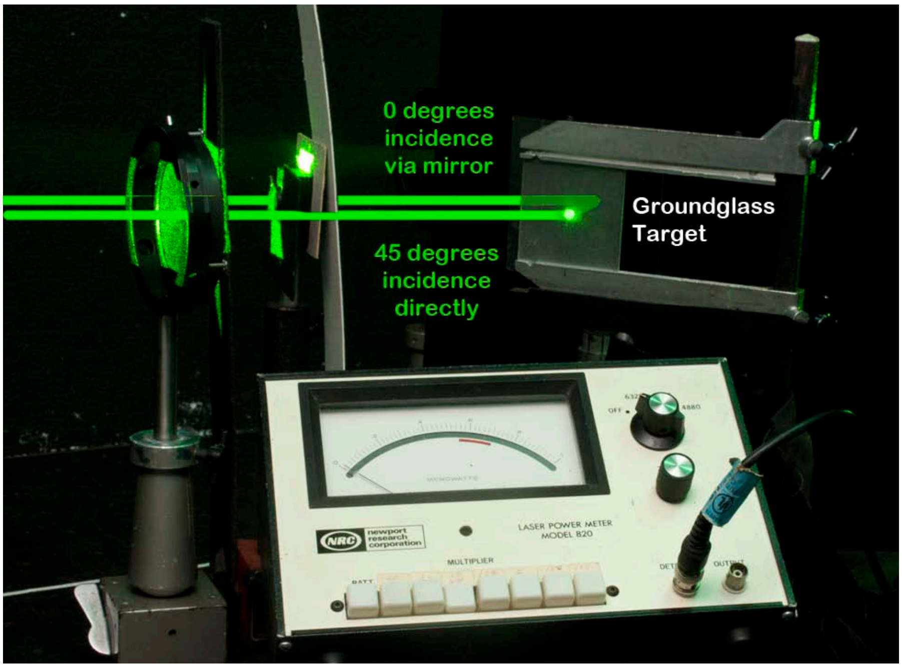


Figure 6: The irises were translated in the beam so that their projections were centered on a piece of groundglass.

The size of the iris was chosen so that it would be large enough to sample a decent chunk of hologram to average out irregularities, and accommodate any ellipticizing of beams. The center of the plate is where the Beam Balance Ratio was measured to be unity, so it is the prime filet of the hologram.

The aperture size was further refined so that the free space travelling light (with glass in the plateholder) would read full scale deflection on the Newport Model 820 Power Meter. Then the first order diffraction figure in the Excel Spreadsheet derived table becomes the diffraction efficiency in percent of the incident light, accounting for loss due to reflection off the hologram's surfaces. The power meter's detector could then be placed in one of 2 positions, and collect the light diffracted into the two different first orders and light not diffracted by the two zero order transmission.

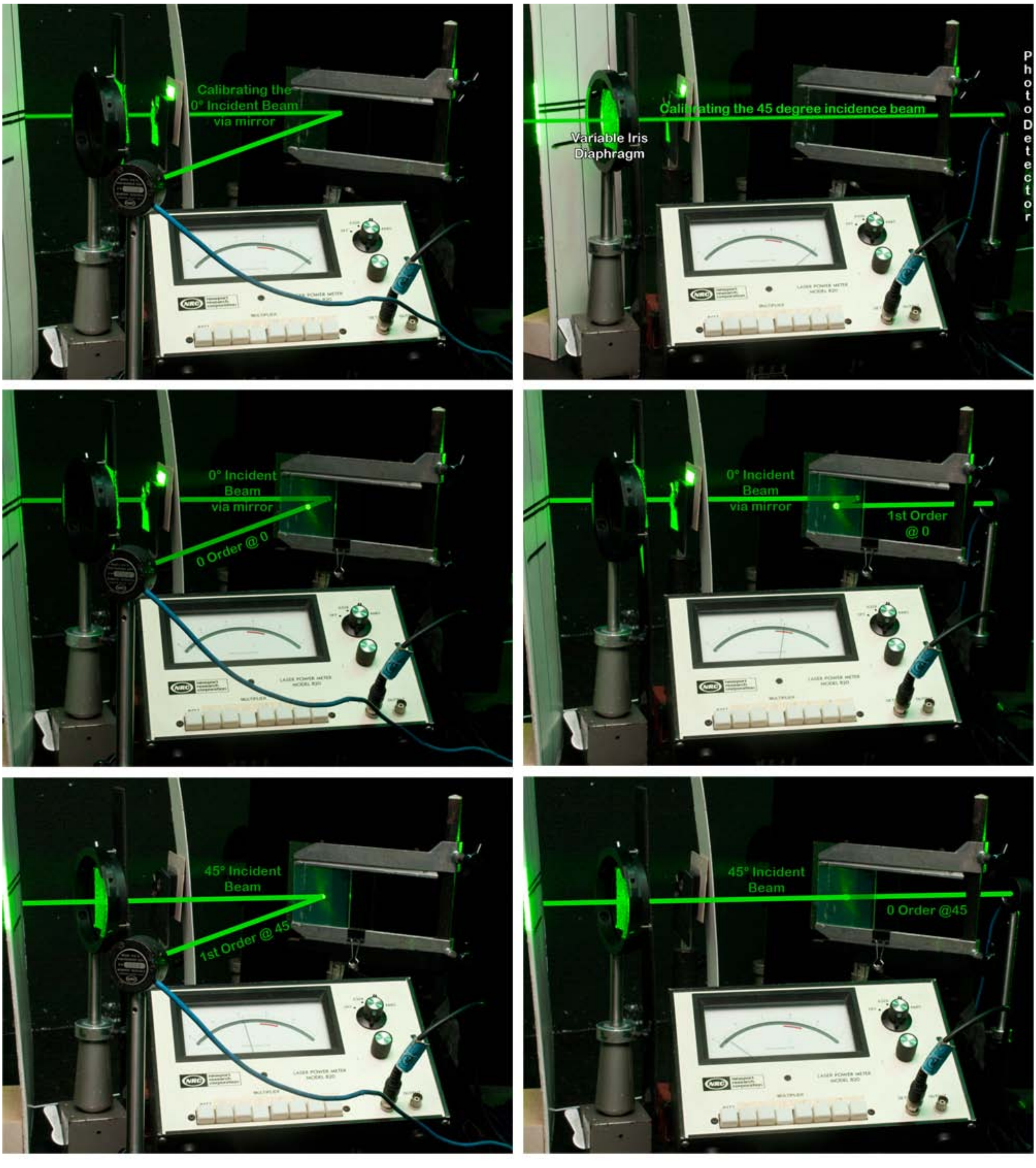


Figure 7: Left column, readings taken at Position A: top, 0° incidence calibration; middle, reading 0 order transmission at 0° incidence; bottom, reading 1st order at 45° incidence. Right column: top, calibrating 45° incidence beam; middle, reading 0° incidence 1st order; bottom, reading 45° 0 order transmission.

3. DATA

3.1 Trials

Here are tables for the test exposure series on Sphere-S GEO-3 plates at the various recording wavelengths, as measured in the above rig.

At 532 nm, 1’ development time, exposures in µJ/cm²:

SAMPLE #	0 ORDER @ 0	1st ORDER @ 0	0 ORDER @45	1st ORDER @ 45	EXPOSURE
59	22	44	18	40	1600
60	8	56	8	50	2200
61	8	64	8	48	3200
62	6	52	6	44	4500

Since 100 units of light were available without the hologram in position, the 1st order values are directly translatable into diffraction efficiency percent! (If you want to take into account the effect of reflection off the surface of the hologram, multiply the first order results by 1.04)

The sum of the 0 and 1st orders do not add up to 100, so there is about a quarter of the incident light lost due to spurious holographic images and scatter. For instance, for sample #61, 8% of the incident light passed through as the Zero Order at Zero degrees incidence, plus 64% diffracted into the First Order at the same time, leaving 28% of the light unaccounted for. Here is a ray trace of some of the spurious images for a similarly recorded grating at 633 nm.

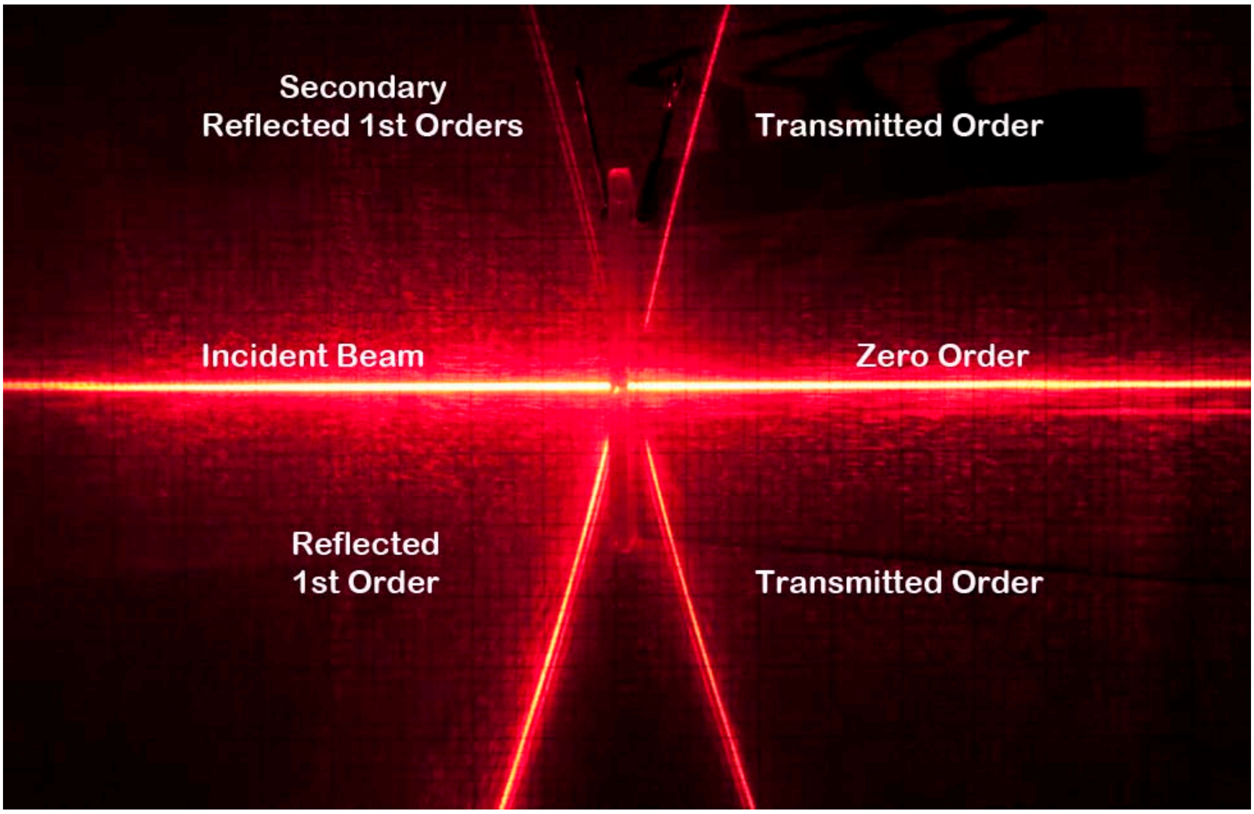
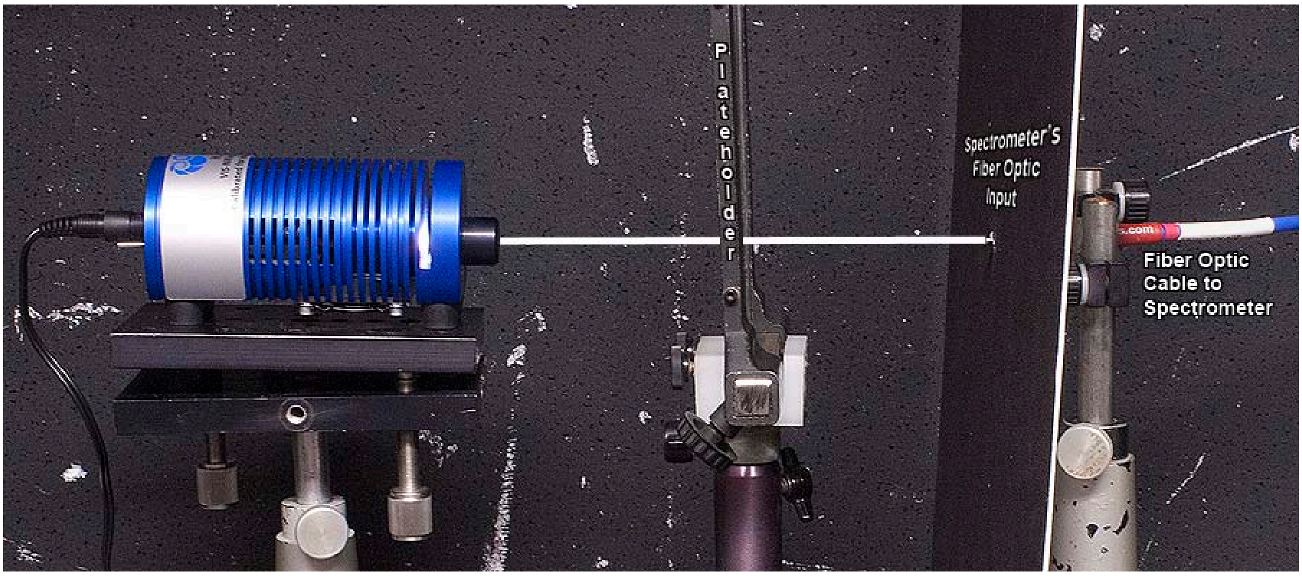


Figure 8: Where the missing readings are going. (HOE recorded at 0° and 70° incidences.)

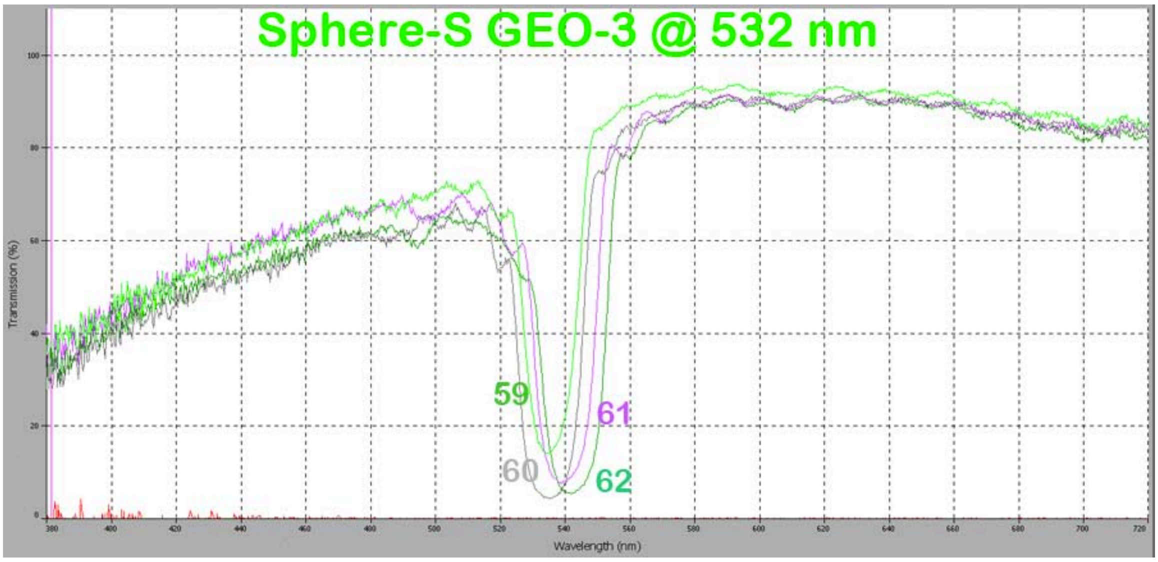
During this project I had access to an Ocean Optics Jaz spectrometer. The hologram was interrogated by it in this set up:



A calibrated black body radiator, Ocean Optics HL-3, feeds light into the collecting fiber optic, which delivers it to the spectrometer housing. The hologram is replayed at normal incidence, which is an angle that is consistently repeatable, by looking over the shoulder of the light source and verifying that the reflection of the output of the black body source is coincident on the fiber optic's input.

The plate could be translated in grooved holder to map out regions of diffracted interest. The holographic plateholder could rock the hologram to control its y-axis pitch, and a rotation stage could rotate the x-axis's yaw, useful for measuring changes in the replay angle. Z-axis roll was not an issue.

The data was taken in the Jaz's Transmission Mode, which measures the depletion of the various wavelengths compared to a previously calibrated baseline at the top of the graph, which is marked 100. Here are scans of the samples from the table above, and the 0 order depletion in the scan's table is in good agreement with the per cent transmission in the table above!



The depth of these scans does not necessarily indicate absolute diffraction efficiency. #60 in the scan above has the deepest dip, looking to be transmitting only about 6%, but the missing 94% is not seen in the diffracted first order in the table above, only 56%. The rest is lost due to spurious images as shown above or scatter.

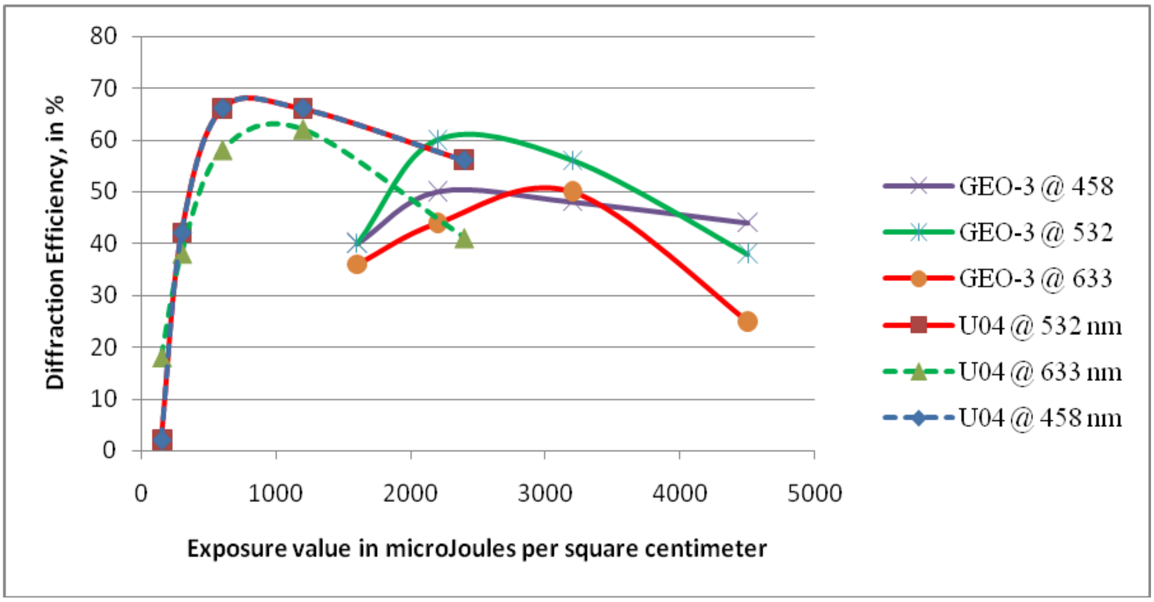
The Rayleigh scatter equation is roughly graphed in the above scans. When the instrument is set up and calibrated, its parameters are adjusted so that the black body radiator's curve is normalized to the 100% horizontal scale line. But the transmission curve of the hologram has the shape of Lord Rayleigh's 4th order polynomial that takes wavelength to that power! More light is lost to scatter at the blue end of the spectrum. One wishes that there were a way to measure grain size using this artifact.

The usefulness of these scans is in checking the replay wavelength and bandwidth. For the most part these samples retained the fringe spacing of the recording wavelength as evidenced by the dip at 532 nm +/- 5nm. Each sample number was a separate plate, so the wavelength variation may be due to operator error when lading the plate in recording or replay.

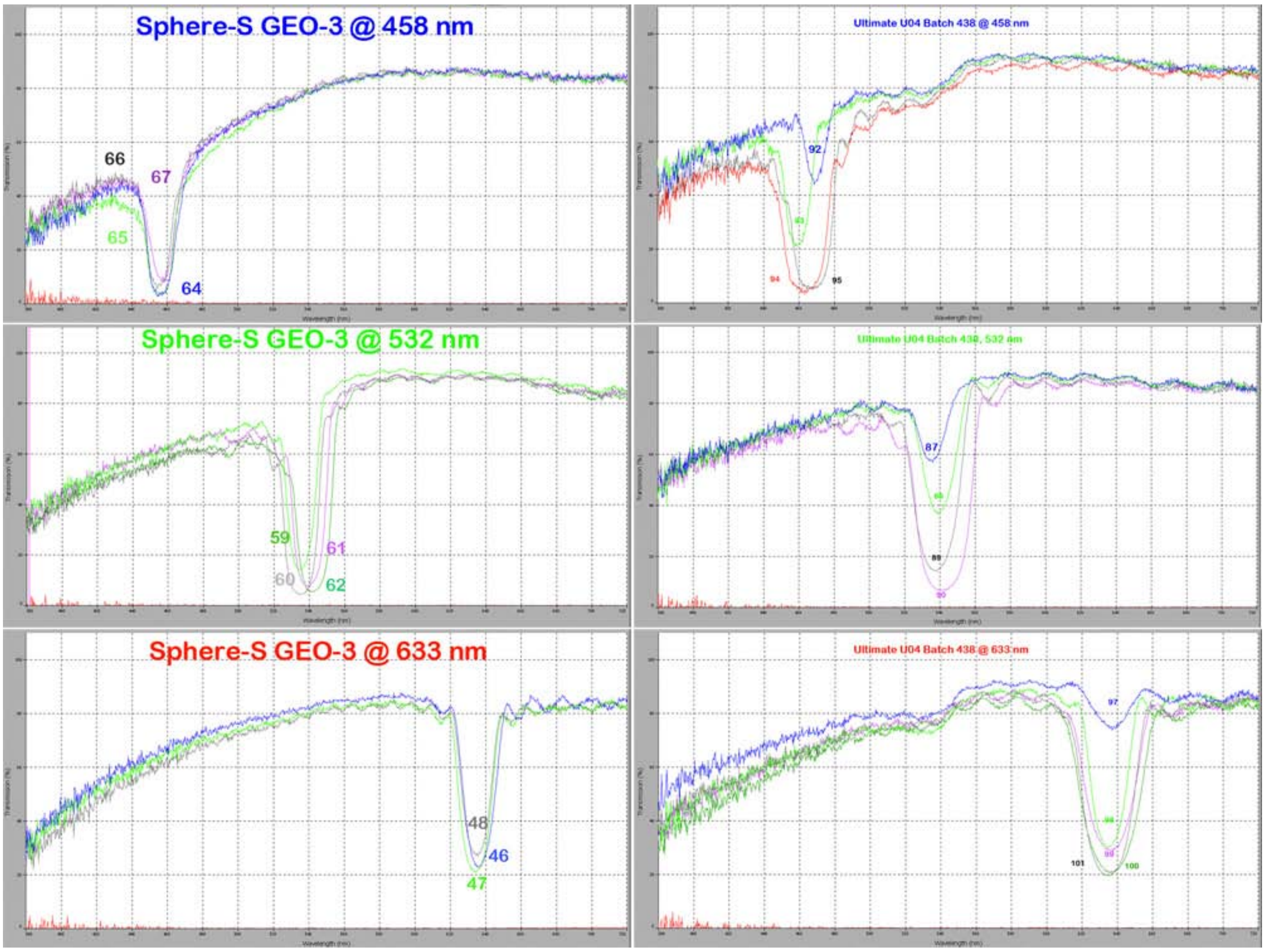
Similarly the same measurements were taken for holograms recorded at 458 and 633 nm on the GEO-3, plus all three wavelengths on Ultimate U-04. Here is the table with all the measurements.

SAMPLE	EXPOSURE	0 ORDER @ 0	1st ORDER @ 0	0 ORDER @45	1st ORDER @ 45
GEO-3 @ 458	1600	16	34	3	40
GEO-3 @ 458	2200	10	62	5	60
GEO-3 @ 458	3200	10	58	8	56
GEO-3 @ 458	4500	12	44	10	38
GEO-3 @ 532	1600	22	44	18	40
GEO-3 @ 532	2200	8	56	8	50
GEO-3 @ 532	3200	8	64	8	48
GEO-3 @ 532	4500	6	52	6	44
GEO-3 @ 633	2200	32	44	35	44
GEO-3 @ 633	3200	16	45	16	45
GEO-3 @ 633	4500	16	30	28	25
U04 @ 458	150	72	2	66	2
U04 @ 458	300	18	42	22	42
U04 @ 458	600	4	58	20	66
U04 @ 458	1200	6	50	7	66
U04 @ 458	2400	8	50	6	56
U04 @ 532	150	58	18	58	18
U04 @ 532	300	38	34	40	38
U04 @ 532	600	18	54	20	58
U04 @ 532	1200	18	54	18	62
U04 @ 532	2400	28	22	28	41
U04 @ 640	150	75	12	80	10
U04 @ 640	300	36	44	40	46
U04 @ 640	600	20	60	24	60
U04 @ 640	1200	25	56	25	60
U04 @ 640	2400	26	40	40	36

Here's the data above graphed, for the 1st order diffraction at 45° incidence:



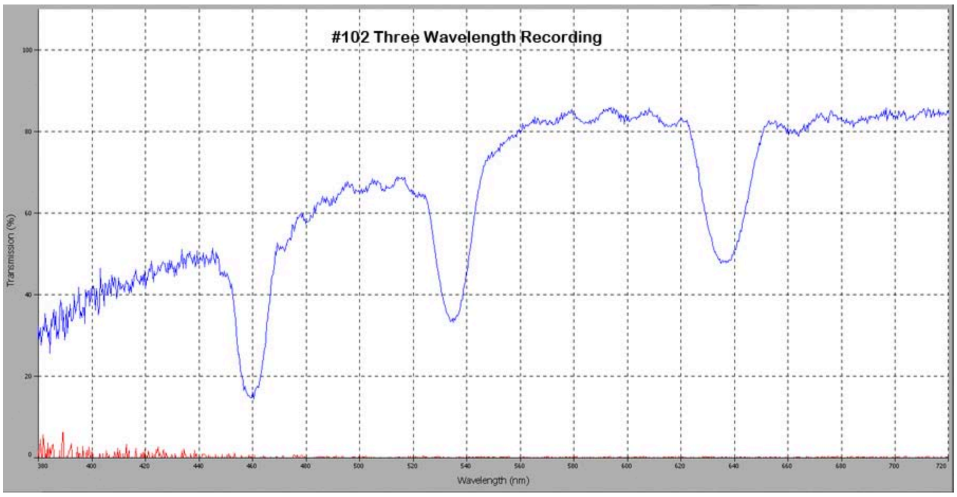
Spectral scans of the bandwidths and wavelength accuracy of the above:



A plate of Ultimate U04 was exposed to all 3 wavelengths and these readings were taken:

SAMPLE #	EXPOSURE	0 ORDER @ 0	1st ORDER @ 0	0 ORDER @ 45	1st ORDER @ 45
102	300 R	52	30	56	28
102	300 G	35	38	38	34
102	300 B	18	46	16	32

And the scan of the "white" replay:



4. CONCLUSIONS

The Single Beam Reflection Hologram of a Mirror technique can record some useful Holographic Optical Elements, if for no other reason than to duplicate this experiment for measuring diffraction efficiency of most any holographic recording material. Although a collimated beam was used for this set up, it does not necessarily need to be so.

A calibrated power meter is not necessary either, although it helps when publishing exposure data that might conceivably be duplicated in other labs. But the determination of the diffraction efficiency can be done with any photo detector, like a silicon cell or photo resistor simply plugged into a VOM, as it is simply the ratio of diffracted beam to incident beam.

Not everyone happens to have a spectrometer at their home lab, but if you got 'em, smoke 'em. It is very useful for seeing the replay bandwidth of the HOE, and can be applied to any reflection hologram, image or Optical Element. There is a real danger for using the transmission curve of the sample for evaluating diffraction efficiency, although they are related. But some manufacturer's do use them in their advertising!

From the above data, it appears that the Sphere-S GEO-3 is almost as efficient at Ultimate U04, but needing quite a bit more light! Unfortunately, Sphere-S GEO-3 is no longer available.

5. APPENDIX

5.1 Processing

The Ultimate Holographic Plates were processed in Ultimate Developer and Bleach, which were purchased from the Ultimate Holography Web Store[1]. The Sphere-S plates were processed in JD-4 Developer[2] and Ultimate Bleach.

REFERENCES

[1] www.ultimate-holography.com/
[2] www.photoformulary.com
[3] www.edweslystudio.com