



University College Dublin

An Coláiste Ollscoile, Baile Átha Cliath

PHYC20090 Electronics and Devices

Experiment No.9 Holography

24 February 2025

by Joana C.C. Adao (Student No. 23311051)

With Ananya L.



Contents

Abstract	1
1 Theory	1
1.1 Recording and Reconstruction of Holograms	1
1.2 Amplitude and Phase	2
1.3 Fourier Transforms	3
1.4 Properties of Laser Light in Holography	4
1.4.1 Monochromaticity	4
1.4.2 Coherence	5
1.4.3 Intensity and Directionality	5
1.5 Types of Optical Holograms	6
1.5.1 Transmission Holograms	6
1.5.2 Reflection Holograms	7
1.6 How Shape, Design and Dimension Affect the Hologram	7
1.7 Applications of Holography	7
2 Methodology	7
3 Results and Calculations	7
4 Conclusion	8
References	9
List of Figures	10
List of Tables	10

1 Theory

1.1 Recording and Reconstruction of Holograms

Holography is a technique that can record and reconstruct an image based on the "total information" content of the light (wavefronts of light) scattered by the object. These are the basic parameters that describe the light, wavelength, amplitude, phase, polarisation, and velocity. For holography, only the phase and amplitude of the light are recorded. This process can be understood via Fourier transforms (see §1.3) [1, 2, 3, 4]. Visually, the hologram can be described as being as a diffraction screen that diffracts light in such a manner that accurately reconstructs the original object when suitably illuminated [2]. The phase and amplitude information is preserved by a "reference beam" and its interference with the light being reflected off the object's surface [1, 3].

Recording a hologram requires the presence of the "object beam", which illuminates the object and reflects onto the recording material (typically an emulsion photographic plate for optical holography), and the "reference beam", the light from an apparent source that shines directly onto the recording material [1, 2] (see Figure 1). These beams interfere to create an interference pattern that is recorded onto the recording material (see Figure 2). Precise positioning of the laser source, beam splitter, mirrors, and emulsion photographic plate is necessary as it determines the fringe spacing of the interference pattern. Therefore misalignments affect the clarity and resolution of the final hologram [1, 4].

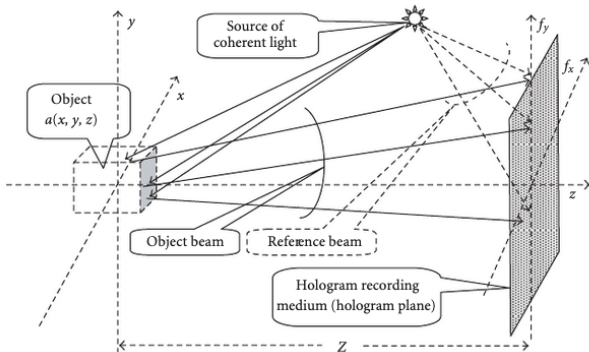


Figure 1: sample caption [5].

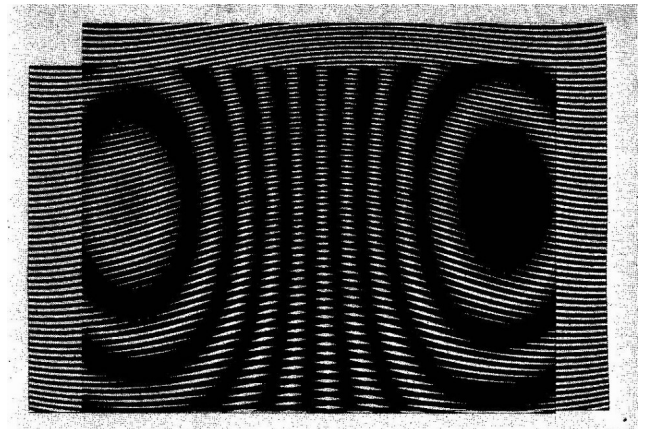


Figure 2: sample caption [6].

Reconstructing a hologram is through diffraction, and it is found that the spacing of the interference fringe are of the correct size (typically between 0.4 to 0.7 microns) to give the desired diffraction effects [1]. The resulting wave structure is then identical to the original, a reconstruction of the original object in 3D detail. A "reconstructing beam", typically the

original source reference beam or light of similar coherency, illuminating the photographic plate in the direction of the original source is what allows one to be able to see the hologram [1]. The reconstructed can be seen moving through parallax effects when the angle of viewing is shifted. The existence of this parallax is what indicated whether the object has three-dimensions [1].

1.2 Amplitude and Phase

Traditioinal photography methods differ from holography in the sense that with holography the phase information is also retrieved, unlike photography where only spatial distribution of light intensity (amplitude) is considered which is averaged over all phases of light [4].

The **amplitude** of a wave is defined as the max displacement of the wave [7]. For a hologram the amplitude variations will affect primarily the contrast of the recorded interference pattern, influencing the final hologram quality [1, 8]. Most hologram reconstruction methods assume pure amplitude, but most real-life objects affect amplitude scattering and are therefore wavelength-dependent, meaning amplitude is essential for accurate holographic image reconstructions [8].

The **phase** of a wave determines where the electric field is in an oscillation cycle [9]. The optical wave can be described with a phasor (complex amplitude), which relates the optical phase to the complex phase. A plane wave propagating in the z-direction can be described with $Ae^{i(\omega t - kz)}$ (see §1.3). Interference strongly depends on optical phases [9]. It is the phase encodement that makes a hologram appear to have a three-dimensional structure due to the phase differences in the interference pattern [9].

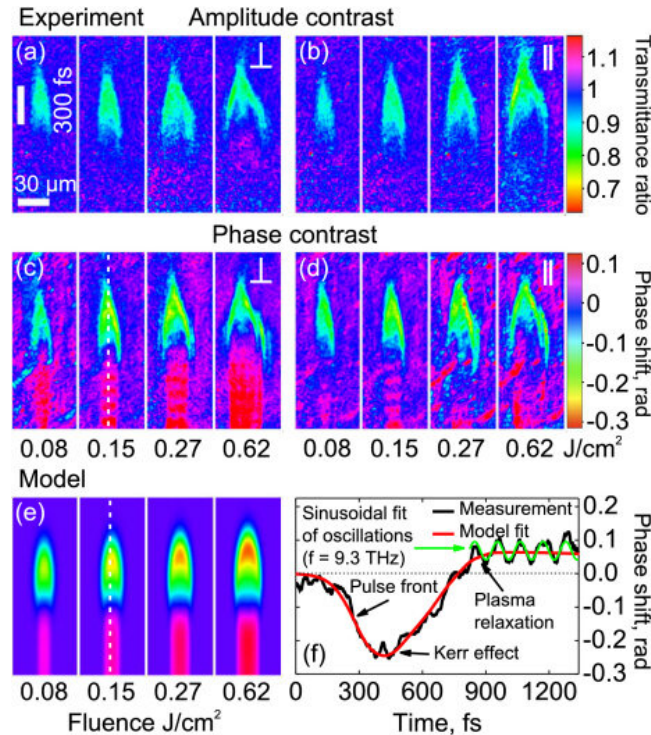


Figure 3: Comparison of amplitude (a-b) and phase (c-d) contrast in holography. Modeled phase images (e) and cross-sections (f) of experimental (c) phase images [10].

The difference between the amplitude and phae contrasts in holography are depicted in Figure 3, comparing the experimental (a-d) and modeled (e) reconstructions. Amplitude contrast images (3a-b) show variations in intensity (amplitude) which affects the trasmittance ratio,

while phase contrast images (3c-d) show variations in phase (phase shifts), affecting the structural reconstruction accuracy [8, 10]. The modeled image (3e) illustrates how amplitude and phase contribute to the final reconstruction of the holographic image, with the phase graph (3f) showcasing the spatiotemporal evolution of the phase shift [10].

1.3 Fourier Transforms

Consider the reflected waves as seen in Figure 4. The detailed nature of this "object beam" is dependent on the object's shape and surface characteristics. Taking a general approach, describe the object beam as a superposition (combination) of plane waves,

$$\psi_0(r, t) = A_0 \iint F_0(k_x, k_y) e^{i(\omega t - k_x x - k_y y - k_z z)} dk_x dk_y$$

where $(k_x^2 + k_y^2 + k_z^2)^{1/2} = k = \lambda/2$. Suppose we have permitted this wave ψ_0 to interfere with a reference beam given by

$$\psi_1(r, t) = A_1 e^{i(\omega t - k z)}$$

and have recorded the resulting intensity pattern on a photographic plate positioned in the plane $z = 0$. The intensity recorded on the plate is then

$$I(x, y) = |A_1 + A_0 \iint F_0(k_x, k_y) e^{-i(k_x x + k_y y)} dk_x dk_y|^2$$

Expanding the right-hand side of this equation, we will have terms proportional to $|\psi_0|^2$, $|\psi_1|^2$, and $|\psi_0 \psi_1^*|$.

Assuming that the reference beam is much more intense than the object beam (ie. $|\psi_1| \gg |\psi_0|$), then the term in $|\psi_0|^2$ can be ignored, and the intensity can be approximated as

$$I(x, y) \approx |A_1|^2 + A_0 A_1^* \iint F_0(k_x, k_y) e^{-i(k_x x + k_y y)} dk_x dk_y + A_1 A_0^* \iint F_0(k_x, k_y) e^{+i(k_x x + k_y y)} dk_x dk_y$$

The transmission function for a developed plate can be expressed as $T(x, y) = 1 - \gamma I(x, y)$ where γ is a function of the exposure and developing processes. Therefore, the hologram's transmission function is

$$T(x, y) = C_0 - \gamma A_0 A_1^* \iint F_0(k_x, k_y) e^{-i(k_x x + k_y y)} dk_x dk_y - \gamma A_1 A_0^* \iint F_0(k_x, k_y) e^{+i(k_x x + k_y y)} dk_x dk_y$$

where C_0 is a constant. Essentially, the hologram contains both scaled versions of the two-dimensional Fourier transform of the object beam and its inverse, superimposed on each other. When this hologram is illuminated with a plane wave like the original reference beam, another Fourier transformation occurs, which leads to

$$\psi(r, t) = \iint F(k'_x, k'_y) e^{i(\omega t - k'_x x - k'_y y - k'_z z)} dk'_x dk'_y$$

where, according to Fourier optics,

$$F(k'_x, k'_y) = \left(\frac{1}{2\pi}\right)^2 \iint T(x, y) e^{i(k'_x x + k'_y y)} dx dy$$

The three terms that make up $T(x, y)$ obliquely integrate as delta functions (unlike the ignored $|\psi_0|^2$ term, which would not behave as such), and we find

$$F(k'_x, k'_y) = -\gamma A_1^* A_0 F_0(k'_x, k'_y) - \gamma A_1 A_0^* F_0^*(-k'_x, -k'_y) + C_0 \delta(k'_x) \delta(k'_y)$$

As a result, when the hologram is illuminated correctly (as in Figure), the emerging wave consists of three parts: (left) a term that is proportional to the original object beam, effectively reconstructing the object in all details of amplitude and phase; (centre) a so-called "twin reconstruction" or "twin image", which can be shown to be the original object beam, reflected across the photographic plate and travelling backwards in time; and (right) an undeflected segment of the reference beam travelling along the z-axis.

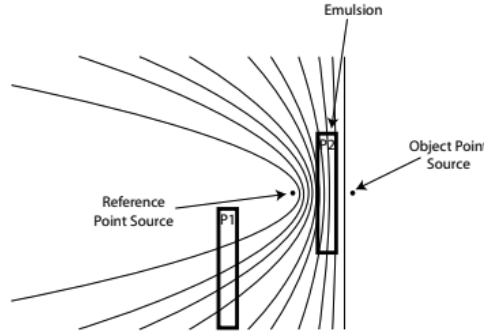


Figure 4: Two-dimensional projection of the interference patterns produced. A photographic plate at P1 would result in a transmission hologram. A photographic plate at P2 would result in a reflection hologram. [3]

1.4 Properties of Laser Light in Holography

Holography relies on the properties of laser light in order to reconstruct and record the necessary three-dimensional images. Lasers are **highly monochromatic, coherent, intense, and coherent** which allows for stable interference patterns. These properties are then what enable the precise encoding of the phase and amplitude information necessary for the reconstruction of the hologram [1].

1.4.1 Monochromaticity

For stable interference the source itself must be stable such that the light is emitted at a single wavelength [11]. Any variation in wavelength would cause the recorded fringes to become "blurred", which affects the clarity of the final hologram, so the laser being monochromatic ensures the fringes remain sharp and stable (well-defined).

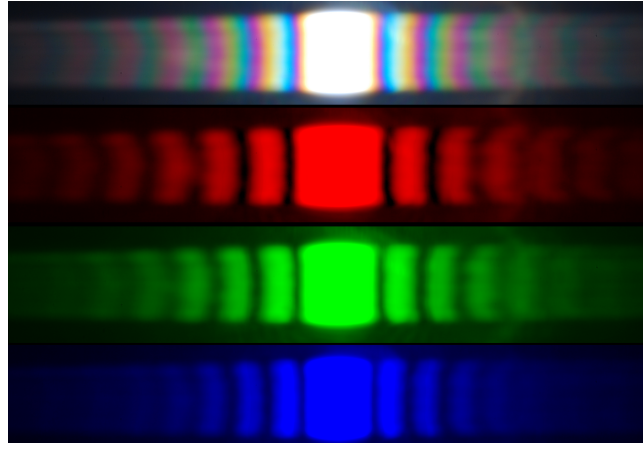


Figure 5: sample caption [12].

As can be seen in Figure 5, the interference patterns from the monochromatic light sources (red, green, blue) appear much sharper than the "blurred" interference pattern of the white light (top) due to the range of wavelengths present in white light.

1.4.2 Coherence

For there to be stable interference the light source must have a fixed phase relationship at different points in time and/or space [13]. This property ensures that the reference and object beams maintain a consistent phase difference, allowing them to interfere and create the fringes of greater and lesser amplitudes [14]. Thus, lasers are used in holography due to their spatial, strong correlation between electric fields at difference points in the beam profile, and temporal, strong correlation between electric fiels at one point at different times, coherences [15] which results in high-quality holographic images.

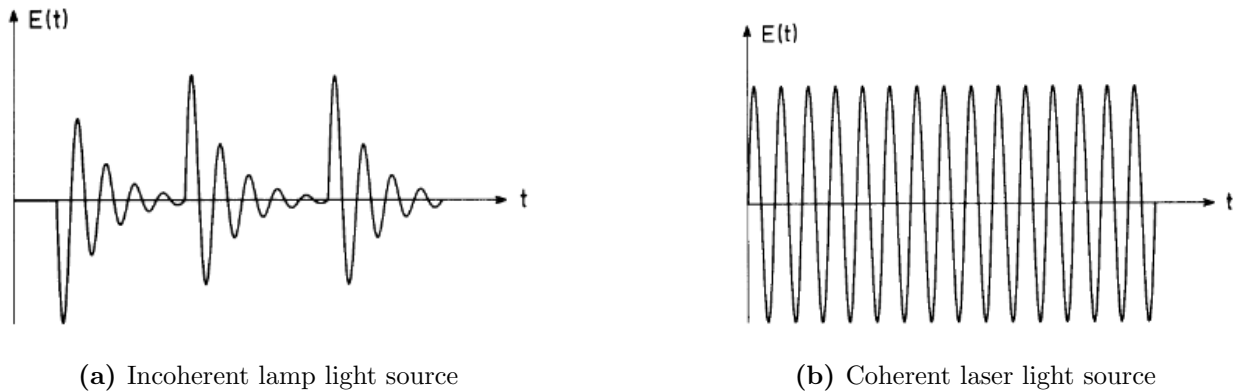


Figure 6: '(a) The electric field strength $E(t)$ of light of a lamp consists of uncorrelated individual wave tracks. (b) Laser light consists of a single coherent very strong wave track.' [16].

A graphical representation of an incoherent (6a) and a coherent (6b) can be seen in Figure 6 above. Visually, it can be understood why a coherent source is necessary for the production of a hologram.

1.4.3 Intensity and Directionality

Laser light possesses both high intensities and high directionality, such laser light does not diffract or spread out like other conventional light sources. High intensities ensure an interference pattern with high contrast and thus the visibility of the final holographic image [6, 16].

The high directionality of the laser source allows for precision over the angles and positioning of the reference and object beams, allowing for the accurate recording of the hologram.

1.5 Types of Optical Holograms

Optical holography is the recording and reconstruction of a hologram using laser light on a holographic plate and demands the presence of a real object in a highly stable and vibration-free recording environments for optimal encoding [2]. The most common types of optical holograms are transmission and reflection holograms.

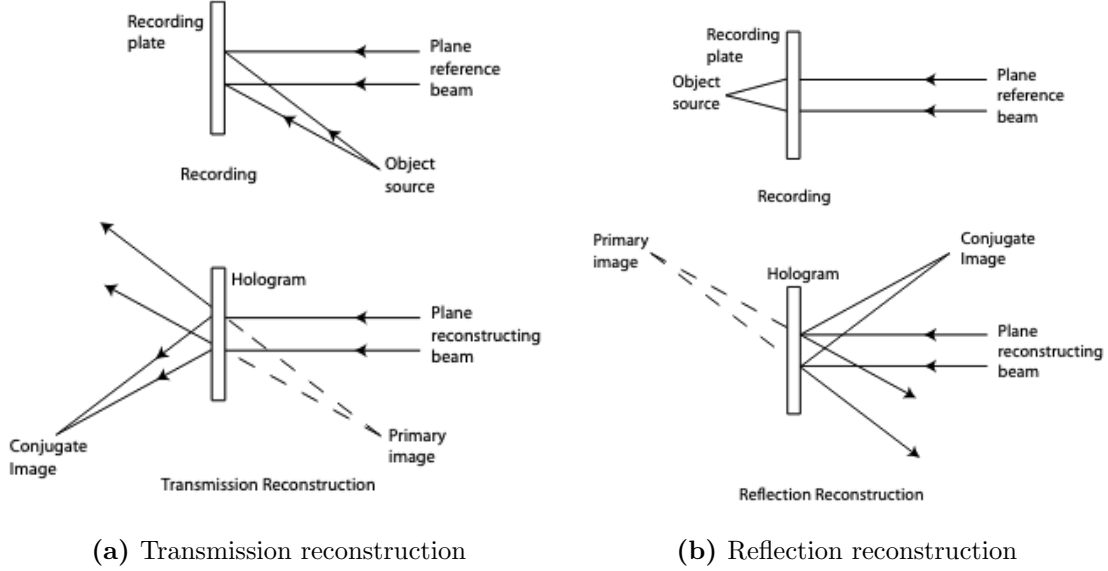


Figure 7: Recording and reconstruction setups for (a) transmission and (b) reflection holograms [3].

1.5.1 Transmission Holograms

Transmission holograms require a monochromatic reconstructive beam (laser) or a single frequency source. This limitation is due to the way the hologram stores its information [3]. See the position of the photographic plate at P1 in Figure 4 and how the interference patterns are produced on that plate. For a transmission hologram the interference is observed to be recorded *perpendicular* to the plane of the photographic plate. Due to this, any frequency of light can then pass through the plate, creating a washed-out appearance of the holograms as every frequency of light subsequently forms an image [3].

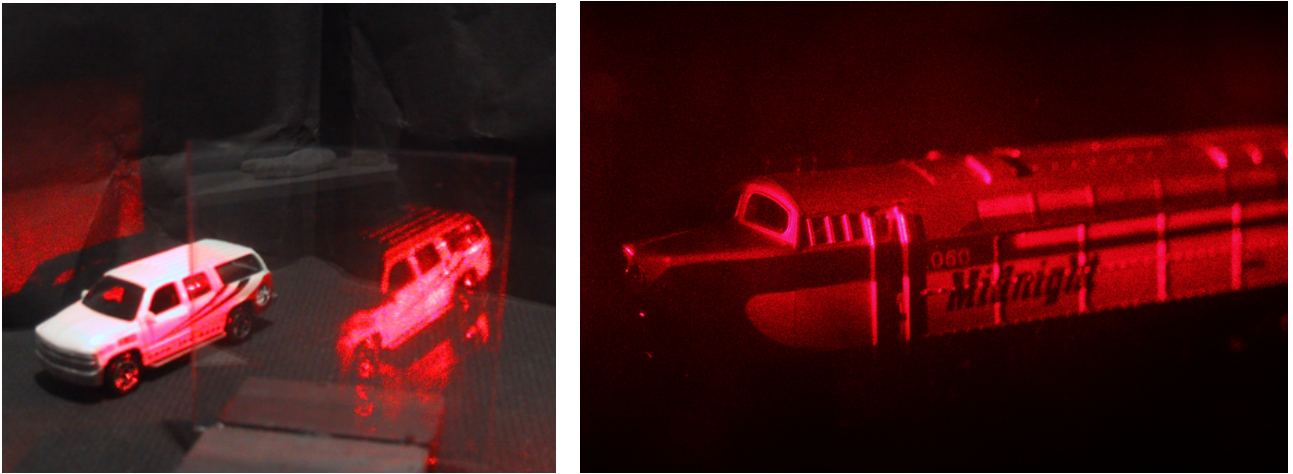


Figure 8: Two transmission holograms, seen with red laser light [17, 18].

1.5.2 Reflection Holograms

Reflection holograms obtained their name due to the fact that they reflect a reconstruction of the object beam to form an image rather than transforming the reconstructive beam into a replica of the object beam [3]. See the position of the photographic plate at P2 in Figure 4 and how the interference patterns are produced on that plate. For a reflection hologram the interference pattern is observed to be recorded *parallel* to the plane of the photographic plate and along the thickness of the emulsion which is essential to reflection holograms (but irrelevant to transmission holograms) [3]. Reflection holograms, unlike transmission holograms, can be seen under white light and thus are also commonly referred to as "white-light holograms".

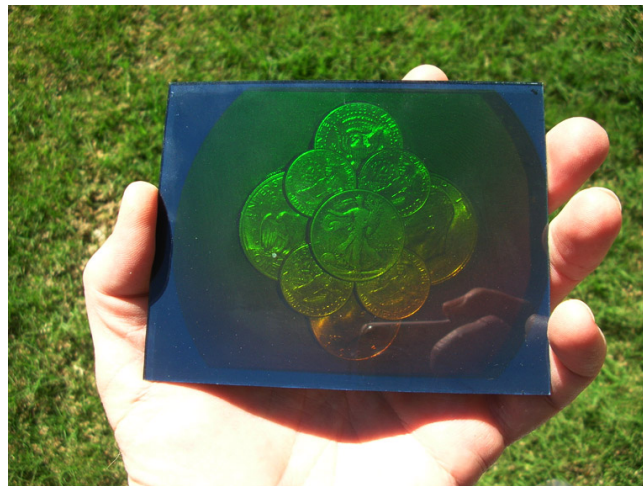


Figure 9: A reflection hologram, seen under sunlight [18].

bragg diffraction or something idk im mad tired rn

1.6 How Shape, Design and Dimension Affect the Hologram

1.7 Applications of Holography

2 Methodology

3 Results and Calculations

4 Conclusion

References

- [1] UCD, *Experiment 9 Holography*, n.d., [Accessed 10 March 2025].
- [2] I. Majid and I. Sugihartono, “Understanding Basics Holography: Review Principle and Recording Technique of Holography,” *Risenologi : Jurnal Sains, Teknologi, Sosial, Pendidikan, dan Bahasa*, vol. 5, pp. 10–25, 12 2020, [Accessed 10 March 2025]. [Online]. Available: https://www.researchgate.net/publication/347912283_Understanding_Basics_Holography_Review_Principle_and_Recording_Technique_of_Holography
- [3] J. H. Taylor, A. Erickcek, and Z. Kermish, “Holography,” in *Physics 312*. Princeton University, 1990-2002, [Accessed 9 March 2025].
- [4] R. Collier, *Optical Holography*. Elsevier, 2013, [Accessed 16 March 2025].
- [5] L. Yaroslavsky, “Discrete transforms, fast algorithms, and point spread functions of numerical reconstruction of digitally recorded holograms,” *Eurasip Book Series on Signal Processing and Communications*, vol. 7, p. 95, 01 2007, [Accessed 15 March 2025]. [Online]. Available: https://www.researchgate.net/publication/265680973_Discrete_transforms_fast_algorithms_and_point_spread_functions_of_numerical_reconstruction_of_digitally_recorded_holograms
- [6] O. Kafri and I. Glatt, *The physics of moiré metrology*. Wiley New York, 1990, [Accessed 15 March 2025]. [Online]. Available: https://www.researchgate.net/profile/Oded-Kafri/publication/37406594_The_Physics_of_Moire_Metrology/links/5b9b9f98a6fdccd3cb54db74/The-Physics-of-Moire-Metrology.pdf
- [7] G. Stark. (2025, March) Characteristics of waves. [Accessed 16 March 2025]. [Online]. Available: <https://www.britannica.com/science/light/Characteristics-of-waves>
- [8] T. Latychevskaia and H.-W. Fink, “Simultaneous reconstruction of phase and amplitude contrast from a single holographic record,” *Optics express*, vol. 17, no. 13, pp. 10 697–10 705, 2009, [Accessed 16 March 2025].
- [9] R. Paschotta, “Optical Phase,” RP Photonics Encyclopedia, 2018, [Accessed 16 March 2025]. [Online]. Available: https://www.rp-photonics.com/optical_phase.html
- [10] N. Šiaulyš, V. Kudriašov, T. Stanislauskas, T. Malinauskas, A. Urniežius, and A. Melninkaitis, “Holographic study of ultrafast optical excitation in GaN film induced by non-linear propagation of light,” *Optics Letters*, vol. 37, pp. 4916–8, 11 2012, [Accessed 16 March 2025].
- [11] P. U. Faculty. (n.d.) Laser Fundamentals. [Accessed 15 March 2025]. [Online]. Available: <https://ehs.princeton.edu/book/export/html/348>
- [12] P. Kuiper. (2009, August) Diffraction sunlight-color channels.jpg. [Accessed 15 March 2025]. [Online]. Available: https://commons.wikimedia.org/wiki/File:Diffraction_sunlight_-_color_channels.jpg
- [13] E. Wolf, *Introduction to the Theory of Coherence and Polarization of Light*. Cambridge university press, 2007, [Accessed 15 March 2025].
- [14] M. Born, E. Wolf, A. B. Bhatia, P. C. Clemmow, D. Gabor, A. R. Stokes, A. M. Taylor, P. A. Wayman, and W. L. Wilcock, *Elements of the theory of interference and interferometers*. Cambridge University Press, 1999, p. 286–411, [Accessed 15 March 2025].

- [15] R. Paschotta, “Coherence,” RP Photonics Encyclopedia, 2007, [Accessed 15 March 2025]. [Online]. Available: <https://www.rp-photonics.com/coherence.html>
- [16] H. Haken and . Unknown, *Laser light dynamics*. North-Holland Amsterdam, 1986, [Accessed 15 March 2025]. [Online]. Available: http://inis.jinr.ru/sl/vol2/Physics/_%CE%EF%F2%E8%EA%E0,%DD%EB%E5%EA%F2%F0%EE%E4%E8%ED%E0%EC%E8%EA%E0/Haken,_Laser_light_dynamics,1985a.pdf
- [17] A. Jeong and T. H. Jeong. (2005-2025) How to Make Transmission Holograms. [Accessed 16 March 2025]. [Online]. Available: <https://www.integraf.com/resources/articles/a-how-to-make-transmission-holograms>
- [18] E. Chesak. (2016) A Different Kind of ”Photography”. [Accessed 16 March 2025]. [Online]. Available: <https://www.lifepixel.com/photography-inspiration/different-kind-photography>

List of Figures

1	sample caption [5].	1
2	sample caption [6].	1
3	Comparison of amplitude (a-b) and phase (c-d) contrast in holography. Modeled phase images (e) and cross-sections (f) of experimental (c) phase images [10]. . .	2
4	Two-dimensional projection of the interference patterns produced. A photographic plate at P1 would result in a transmission hologram. A photographic plate at P2 would result in a reflection hologram. [3]	4
5	sample caption [12].	5
6	’(a) The electric field strength $E(t)$ of light of a lamp consists of uncorrelated individual wave tracks. (b) Laser light consists of a single coherent very strong wave track.’ [16].	5
7	Recording and reconstruction setups for (a) transmission and (b) reflection holograms [3].	6
8	Two transmission holograms, seen with red laser light [17, 18].	7
9	A reflection hologram, seen under sunlight [18].	7

List of Tables