View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by NASA Technical Reports Server

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

AD-787 615

VACUUM ULTRAVIOLET HOLOGRAPHY

G. C. Bjorklund, et al

Stanford University

Prepared for:

Advanced Research Projects Agency
National Aeronautics and Space Administration

June 1974

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

AD787615

VACUUM ULTRAVIOLET HOLOGRAPHY

by

G. C. Bjorklund, S. E. Harris, and J. F. Young

Preprint

M. L. Report No. 2317

June 1974

Contract Nos.

NGL 05-020-103

N00014-67-A-0112-0044

ARPA - CMR - DAHC15-73-G15

submitted to

Applied Physics Letters

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

DDC
RECEIVED
OCT 8 1974
B

Microwave Laboratory
W. W. Hansen Laboratories of Physics
Stanford University
Stanford, California

VACUUM ULTRAVIOLET HOLOGRAPHY[*]

by

G. C. Bjorklund, S. E. Harris, and J. F. Young
Microwave Laboratory
Stanford University
Stanford, California 94305

ABSTRACT

We report the first demonstration of holographic techniques in the vacuum ultraviolet spectral region. Holograms were produced with coherent 1182 Å radiation. The holograms were recorded in polymethyl methacrylate and read out with an electron microscope. A holographic grating with a fringe spacing of 836 Å was produced and far-field Fraunhofer holograms of sub-micron particles were recorded.

---

[*] Work supported in part by the National Aeronautics and Space Administration under NASA Grant NGL-05-020-103, by the Joint Services Electronics Program through the Office of Naval Research under Contract N00014-67-A-0112-0044, and by the Advanced Research Projects Agency through the Center for Materials Research at Stanford University under Contract DAHC15-73-G15.

VACUUM ULTRAVIOLET HOLOGRAPHY

by

G. C. Bjorklund, S. E. Harris, and J. F. Young
Microwave Laboratory
Stanford University
Stanford, California 94305

Fixed frequency and tunable sources of coherent vacuum ultraviolet radiation have recently been developed.[1-2] The application of these sources to holography holds promise for increased resolution in holographic microscopy and holographic image projection.

In this Letter we report the production of holograms with coherent VUV radiation at a wavelength of 1182 Å. The holograms were recorded as surface relief patterns in polymethyl methacrylate (PMMA).[3] PMMA responds to 1182 Å radiation as a positive photoresist with sufficient resolution to record fringes less than one wavelength apart. This resolution capability makes it possible to use simple holographic recording geometries which allow large angles of interference between the reference and object waves and which do not require VUV optical components of diffraction limited quality. Most previous recording geometries proposed for VUV and x-ray holography have involved the use of high quality components to focus the reference beam[4] or object wave[5] in such a way as to cause small angles of interference between the two waves.

We prepared 1400 Å thick layers of PMMA by spinning a 3% solution of PMMA[6] in methyl ethyl ketone at 5000 rpm onto 1" diameter quartz flats. The flats were then baked for 1/2 hour at 170°C. After exposure to the 1182 Å radiation, the flats were immersed for 1 minute in a developing solution of 100% methyl isobutyl ketone at 24°C, rinsed with isopropyl alcohol, and blown dry with nitrogen.

The 1182 Å radiation, obtained as the 9th harmonic of the 10,640 Å Nd:YAG laser line,[1] was in the form of single pulses of 12 psec estimated duration and 0.4 cm estimated coherence length. The beam then passed through a LiF window into a He purged glove box in which all subsequent operations with the 1182 Å radiation were conveniently performed. After isolation of the 1182 Å radiation, the available energy per pulse was approximately 0.3 μJ, corresponding to an average power of 1.5 μW at a typical repetition rate of 5 pps.

A series of experiments were carried out to determine the resolution capability and sensitivity of PMMA. Holographic gratings were produced in PMMA by recording the linear fringe patterns resulting from the interference of two plane waves of 1182 Å radiation. Several different fringe spacings were produced by varying the angle of interference. The finest fringe spacing produced was 836 Å (Fig. 1). The largest gratings which were produced were approximately 2 mm^2 in area. All of the gratings were produced by the use of multiple pulses of 1182 Å radiation. Typical exposures lasted 1000 sec and involved the superposition of the fringe patterns produced by 5000 separate pulses. A minimum cumulative exposure of about 100 mJ/cm^2 was found to be necessary.

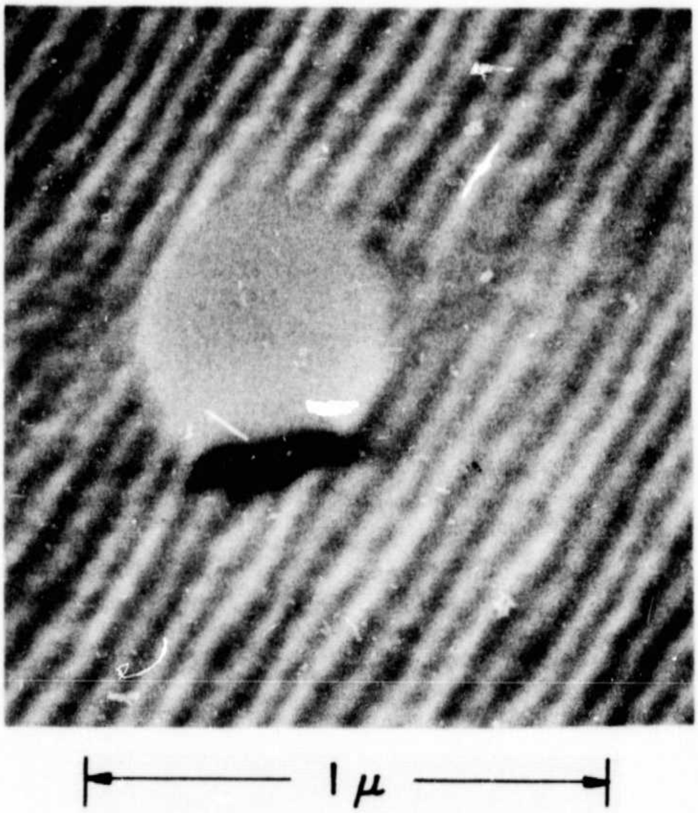

FIG. 1--SEM read out of 836 Å spaced fringes produced in PMMA by 1182 Å radiation. The round object is a 0.500μ diameter latex sphere placed on the fringes after development for magnification calibration. (25 KV electron potential, 80° sample tilt.)

No attempt was made to spatially filter or collimate the interfering beams and thus the fringes were neither perfectly linear nor exactly uniform in depth and spacing. Examination of several of these gratings with a scanning electron microscope (SEM) shows that the PMMA was never developed down to the substrate. This was true even for larger exposures (over 1000 mJ/cm^2) and longer development times, indicating that the 1/e penetration depth of the 1182 Å radiation into PMMA is less than 600 Å.

In another series of experiments, 1182 Å radiation was used to record far-field Fraunhofer holograms of small particles. The particles were latex spheres[7] of carefully controlled diameters ranging from 1.305μ to 0.365μ. The particles were supported on 100 Å thick carbon films (35% transmitting to 1182 Å radiation) which were in turn supported by 200 mesh copper grids. These grids are of the type which is commonly used to support specimens for transmission electron microscopy.[8] A letter pattern, formed by some of the grid bars, permits positive identification of each grid square and thus of each particle. Each grid was turned so that the carbon film faced the PMMA layer and then lightly placed in direct contact with the PMMA surface. The carbon film and the top surface of the PMMA layer were actually separated by small gaps due to imperfect physical contact. These small gaps were sufficient to result in some of the latex spheres being suspended distances on the order of 25μ above the PMMA layer. A 1 mm^2 area of each grid was then illuminated at normal incidence with 10^4 pulses of a single beam of 1182 Å radiation.

The 25μ spacing was sufficient to place the PMMA layer in the far-field of the particles. When this far-field condition is satisfied the Fraunhofer diffraction pattern of each particle interferes with the coherent background to form the hologram. This geometry has the advantage that, upon reconstruction, the real image is free of interference from the virtual image.[9] Holograms formed by this method are localized to a small area on the recording medium, with a diameter on the order of the particle distance from the medium. In principle, the coherent illumination could be focused to a spot size equal to the area of a single hologram, thus allowing holograms to be recorded with very small amounts of coherent radiation. For example, 5 μJ of 1182 Å radiation would be sufficient to record a 70μ × 70μ hologram in PMMA. Because the PMMA was still in the near field of each grid bar, geometrical shadows of the mesh and lettering patterns appeared in the PMMA after development and permitted positive location of the hologram of each particle. A SEM was used to read out these holograms.

Figure 2 shows a scanning electron micrograph of the holograms of several 1.305μ diameter spheres. Each hologram is composed of a concentric pattern of circular fringes. The circles in Fig. 2 appear elliptical due to the tilt angle of the PMMA surface with respect to the electron beam. The linear fringes running across the top of the figure are knife edge fringes from the side of a mesh grid bar. The superposition of fringes from separate holograms is evident.

Image reconstruction could be accomplished with a visible wavelength laser or by computer. Aberration-free reconstruction with a visible wavelength laser would require that the hologram fringe pattern be read out by electron microscope, enlarged by a factor $\lambda_{visible}/\lambda_{VUV}$, and then mapped onto film as variations in transmittivity.[10] The reconstructed image would

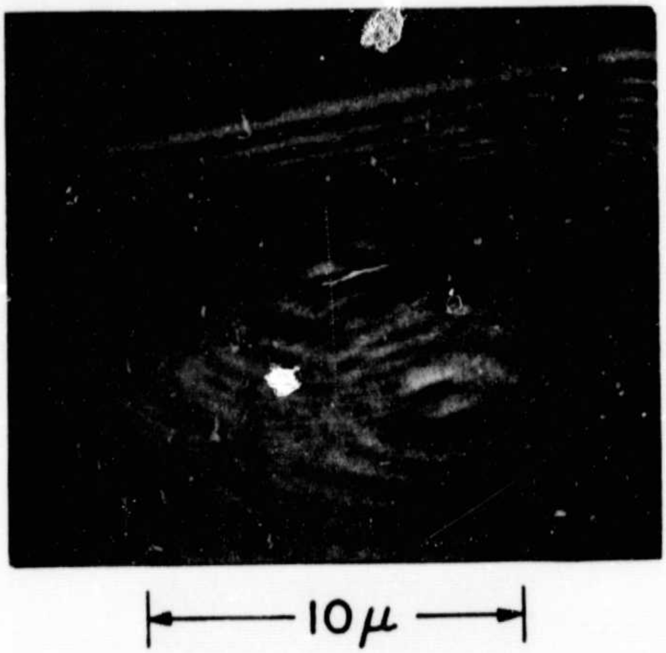

FIG. 2--SEM read out of holograms of 1.305 μ diameter particles (25 KV electron potential, 60° sample tilt).

be magnified by $\lambda_{visible}/\lambda_{VUV}$. Computer reconstruction would require digitilization of the electron microscope read out and numerical evaluation of the Fresnel integrals describing the reconstruction process.[11] The small size of these holograms relative to the necessary sampling interval would permit this numerical evaluation within a reasonable amount of computer time. For example, a 512 × 512 sampling array with intervals of $\lambda_{VUV}/2$ is sufficient to resolve the highest possible spacial frequencies in a $30\mu \times 30\mu$ hologram.[12] Computer reconstruction has the advantages of arbitrary magnification and of the capability of forming separate images of the real and imaginary parts of the object transmittance. Both methods of reconstruction require a linear read out of the hologram fringe depths.

The authors gratefully acknowledge discussions with J. W. Goodman, who suggested the far-field Fraunhofer geometry, G. Haydon, and H. I. Smith, and thank B. Yoshizumi for help with the experimental apparatus. The electron microscopy was performed by R. MacAdam of Applied Space Products, Inc.

REFERENCES

1. A. H. Kung, J. F. Young, and S. E. Harris, Appl. Phys. Letters 22, 301 (1973).
2. R. T. Hodgson, P. P. Sorokin, and J. J. Wynne, Phys. Rev. Letters 32, 343 (1974).
3. D. L. Spears and H. I. Smith, Electronics Letters 8, 102 (1972).
4. G. W. Stroke, D. Brumm, and A. Funkhouse, J. Opt. Soc. Am. 55, 1327 (1965).
5. E. N. Leith, J. Upatnieks, and K. A. Haines, J. Opt. Soc. Am. 55, 981 (1965).
6. Obtained from Esschem Corp., Essington, Pa., mol. wt. 950,000.
7. Obtained from Dow Diagnostics, Indianapolis, Indiana.
8. Obtained from Ernest F. Fullam Inc., Schenectedy, New York.
9. J. B. DeVelis, G. B. Parrent, Jr., and B. J. Thompson, J. Opt. Soc. Am. 56, 423 (1966).
10. R. W. Meier, J. Opt. Soc. Am. 55, 987 (1965).
11. J. W. Goodman and R. W. Lawrence, Appl. Phys. Letters 11, 77 (1967).
12. A. M. Silvestri, Ph.D. Dissertation, "Digital Image Formation and Fourier-Domain Quantization," Stanford University, Stanford, California, 1971.