VOL. 11, NO. 1 JUNE 2000

SPIE's
International
Technical
Group
Newsletter

Holography

Three-color laser for pulsed holography

Color pulsed holography has not been widely used so far because of the rigid requirements on the laser light used. Generation at three wavelengths with high radiation coherence is necessary, pulse duration must be less than the characteristic time for object shifting, and the energy of each part of the three-color radiation must be sufficient to expose the photosensitive plate (several Joules for portraits).

Here we discuss the development of a three-color solid-state laser on phosphate neodymium glass for pulsed holography. The laser is of multicascade design with a single master oscillator. A powerful infrared beam is frequency-converted into green, dark blue, and red, through second and third harmonic generation of neodymium laser radiation, and generation of first anti-Stokes component of the Stimulated Raman scattering respectively. By varying the conditions under which this process takes place, it is possible to redistribute the radiation energy of the system between beams of various colors over a wide range. The energy of each beam can therefore be made sufficient for holographic exposure at that particular wavelength and, together, the beams will make possible color pulsed holograms: color holographic portraits in particular.

Experimental setup and results

The laser has been developed as several different modules: master oscillator; two-cascade pre-amplifier; spatial filter with beam expander; basic channel of amplification; two-cascade Stimulated Brillouin Scattering mirror; nonlinear frequency doubler on a KDP crystal; frequency adder on a KDP crystal; and a cuvette with compressed hydrogen for Stimulated Raman Scattering (SRS).

Master oscillator

Radiation frequency reproduction stability and line width are in many respects determined by a master oscillator. Its design is therefore of fundamental importance for application in large laser systems. Phosphate neodymium has a rather wide luminescence spectrum. Therefore, to obtain generation with narrow spectral line and high spectral stability, it is necessary to add various elements to the basic oscillator.

Our master oscillator has stable spectral and energy parameters:

-pulse duration at half-height: 27ns
-stability of spectral line: 0.1Å
-width of radiation spectrum: 0.01Å
-wavelength: 1054nm
- pulse energy: 100mJ
-instability of energy from pulse to pulse: <10%
-pulses repetition frequency: 0.2Hz

Two cascade pre-amplifier

The energy of the master oscillator output is insufficient to be effectively amplified in a wide-aperture active element. We therefore used a two-passage pre-amplifier with a 10mm-diameter active element. Then, a pair of mirrors enables the cascade required for amplification. These mirrors and a system of reference points allow changes in the oscillator radiation direction to be compensated for during operation without readjusting the rest of the optics. This makes the complex laser steady against vibration and other mechanical and thermal influences.

Spatial filter with expanding telescope

The accumulated spatial distortions are eliminated using a spatial filter consisting of two confocal positive lenses with a pinhole in their point of common focus. The degree of spatial frequency filtration and the profile of the system's output radiation are dependent on the size of the pinhole. The radiation profile desired after spatial filtering is the hyperGauss form—close to rectangular—in order to fill the amplifier's aperture. This allows more effective energy output due to inversion in the active elements and an increase in the efficiency of nonlinear frequency conversion. The spatial filter's telescope also has a beam diameter, after the preamplifier, matched to the later amplification path. The output lens of the telescope sets up the diffraction divergence for the output of the whole laser system.

Basic channel of amplification

The basic channel of amplification consists of two amplifiers, of 20mm and 10mm diameter respectively, divided by a Keppler telescope to match the diameter of the beam with their apertures. We use phosphate glass as the active material because it has a high amplification coefficient when the optical quality of large elements is good. Both of the amplifiers were on one axis with a Stimulated Brillouin Scattering mirror. We chose a traditional lamp to pump the active elements in the basic channel of amplification, as well as in the preamplifier, because the system required large radiation energy. The basic channel of amplification need

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Newsletter now available on-line

Technical Group members are being offered the option to receive the Holography Newsletter in an electronic format. An e-mail notice is being sent to all group members advising you of the web site location for this issue and asking you to choose between the electronic or printed version for future issues. If you have not yet received this e-mail message, then SPIE does not have your correct e-mail address in our database. To receive future issues of this newsletter in the electronic format please send your e-mail address to spie-membership@spie.org with the word HOLOGRAPHY in the subject line of the message and the words "Electronic version" in the body of the message.

If you prefer to continue to receive the newsletter in the printed format, but want to send your correct e-mail address for our database, include the words "Print version preferred" in the body of your message.

Holographic art on the internet

Asked to report on recent developments in holographic art, my initial response was 'not many.' Of course artists continue to use holography, have exhibitions, sell work occasionally and complain about lack of funds, opportunities and so on. No change there. And as to the basic tools and techniques of holography- no earth-shattering breakthroughs of late, although there are some interesting rumblings in the air concerning the use of laser-diodes.

Then it occurred to me. What have all the artists I can think of been spending most of their time on lately? Websites, that's what. And clearly that has been the most significant development of late. Perhaps it is true in all walks of life but, to holographers in particular, the web has provided a superb way of promoting their art and communicating with one another. They can produce comprehensive illustrated catalogues of their work at a fraction of the cost of printing. They can use stereoscopy to show 3D and movie clips to show animation. How fantastic to have a portfolio of your work that anyone can access anytime, from anywhere in the world. No wonder no-one is making any new work, they are all too busy documenting their old work. This may just be a phase, as everyone struggles to establish a foothold, but I am convinced it will prove to be time well spent—as long as they return to their labs at some point.

I have found over the years that proactive marketing of holography—except in areas where there is an obvious, proven need, such as security—is fairly unproductive and that most commissions (and I am talking about display holography in general here, rather than fine art) come about as a result of the client having the brilliant idea to use holography as opposed to someone selling him the concept. So, if your services are well signposted on the Web you stand a good chance of being discovered by the client who has gone out in search of holography and, to his delight, come across a site that offers what he wants.

I had first hand experience of this last year when I was contacted by a major manufacturer of fiber optics, whose advertising slogan was 'architects of light' and who had come to the very correct conclusion that holography was the most appropriate medium with which to attract visitors to his stand at trade fairs. Having apparently looked high and low, he happened upon my website, which at the time was exclusively (and quite uncommercially) devoted to a catalogue of my collection. He concluded that, while I might not be a manufacturer of holograms, I probably knew someone who was. We exchanged email for a while and eventually he visited my gallery where I was able to show him a range of the techniques available. He went away highly enthused and a couple of months later came up with a large commission which I was able to place with an appropriate manufacturer.

You might say that this is not much different from looking up 'holographers' in Yellow Pages—the route taken by most previous clients—but in this case, the client was from another country and I'm guessing would probably not have had access to the Central London directory. More recently, I had an approach from a museum who had heard of my collection—not through the web as it transpired but through the more traditional promotional tool of a postcard set (produced by the Art in Holography2 Symposium[1])—and were interested in discussing an exhibition. I was able to direct them to my website where details of previous exhibitions were catalogued, and within a month I was on a plane with a trunkload of holograms. Without the website, I would probably have had to send slides or catalogues from previous shows: in this case the site did the trick.

It is probably too early to get a realistic picture of the success or otherwise of attempts to sell holographic art over the internet. Individual artists seem to be more reticent in their approach to this and their sites tend to have an appealingly uncommercial style. The few sites I have encountered that claim to be selling holographic art are, by and large, actually selling commercially-produced holograms. They were quite possibly well-designed and technically proficient, but not the sort of work that is going to get holography much credibility in fine-art circles. I intend to remedy this situation in the coming year by offering a selection of work by artists featured in my collection but I suspect that I will be lucky to make any sales online. What I hope, however, is that it will act as a useful starting point: a collector will be able to get some idea of the work that is available prior to deciding whether it is worth his while making the journey to the gallery. Similarly, I intend to preview exhibitions on the web with the website address printed on invitations to the show, the idea being that someone on my mailing list will receive the card and be able to see some of the work online before committing to a visit.

In his paper two years ago,[2] Andrew Pepper reports doing a search in May 1998 on the word 'holography' with the search engine AltaVista and being presented with a choice of 36,650 pages. Almost two years later, in April 2000, I attempted a similar search and was presented with the somewhat confusing result of a mere 27,585 pages. A search on 'holographic art', however, revealed the mind-boggling result of 406,190 pages and when I tried again a couple of minutes later the even more astonishing figure of 429,985 pages. Faced with this abundance of material one might just decide to give up and go down the pub, so as a useful digest I would recommend—if you have not already discovered it—Frank deFreitas' wonderful Holoworld site. In particular, his links page[3] seems to have just about anyone who is anyone listed, and is a great starting point from which to explore the web. And of course I would encourage you to visit my website too!

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http://www.holonet.khm.de/jross.

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Feasibility study for making electron-beam CGHs

Computer-generated holograms (CGHs) are digital holograms recorded using computer-generated interference patterns. CGHs were originally proposed in the 1960s and, since then, researchers have been looking at ways of making them.[1] In the case of CGHs displaying 3D images, interferogram data (IFD) must be calculated and recorded at submicron intervals. In the 1960s, the technology required to realize such holograms didn't exist. Now, fast calculation, of the order of gigaflops, and minute recording with submicron precision are possible because of the development of semiconductor processing techniques. Here, we report on a recent investigation we did into making CGHs using these new technologies.

Figure 1. Reconstructed monochrome images of the CGH under white light. Pictures are taken from the: (a) left, (b) front, (c) right.

At SPIE 's Practical Holography XII in 1998, we reported the trial fabrication of 3D-image CGHs using an electron-beam printing system (EBPS).[2] In that research, the holograms made were bi-level 3D images, such as a set of characters or a simple 3D wire frame object. Trial fabrication of multi-level 3D images was not performed at that time because our method of interferogram modulation, essential to the use of EBPS, was not suitable for that purpose. This is because EBPS is controlled by on-off switching. For it to work, the IFD needs to be transformed into minute rectangle cells with their locations corresponding to that of the fringe.

In Practical Holography XIII in 1999, we reported experimental results with our improved CGH technique.[3] To solve the interferogram problem, pulse-width modulation (PWM) was applied to the interferogram transformation. Here, intensity is quantized into many levels and then the rectangle cell width is determined in proportion to the quantized intensity value. Most recently, in the Practical Holography XIV in 2000, we reported color- and multi-image recorded CGHs were reported.[4] In this work, the chromatic dispersion of the reconstructed images is used in a positive way, and the result is a CGH displaying multi-color images. Further, by using angle selectivity positively, we have made CGHs in which three different 3D images are recorded.

In our method, the CGH fabrication process is mainly composed two parts: calculating and then recording the IFD. To calculate the IFD, first the shape of each object recorded on the CGH is defined as digital data. Secondly, in preparation for calculating the IFD, the geometrical and optical constants of the objects are defined. Thirdly, the IFD values are calculated with the constant values mentioned above.

Recording the IFD is done as follows. First, the IFD is transformed into the rectangle data that is appropriate for EBPS. This transformation is mainly composed of three steps: the quantization of the real number IFD, the modulation of the quantized IFD into the uniform rectangle pulse, and the transformation of the rectangle IFD into the rectangle data appropriate for the EBPS. In this case, pulse-width modulation (PWM) is applied to the modulation at the second step so as to reconstruct image tone. The PWM transforms the intensity of the quantized IFD into rectangular pulse width. In the case of making color CGHs, three IFDs for (RGB color) are processed. In the case of making multi-image CGHs, the IFD for each image is processed in order. Finally, the rectangle data is recorded on a photoresist-coated plate and the CGH is finished.

Figure 1 shows reconstructed monochrome images of a CGH under white light. The divergence angle of the object wave was 20° on each side (horizontal), and 0° (vertical). The incident angle of the reference wave was 40° downward and the wavelength was approximately 643nm. The CGH was 24mm wide and 10mm high. The horizontal and vertical sampling intervals on the CGH were 0.6μm and 0.2μm, respectively. By geometrically and optically processing the original object, the centered DNP logo, the rounded ring, and the small characters in the background can all be observed with an enhanced 3D effect, making the images look similar to conventional holograms. For of color- and multi-image CGHs, please see Reference 4.

From our results, 3D-image CGHs fabricated using electron-beam printing seem to be practical for future commercial use, especially in the optical security field. A feasibility study of meter-scale CGHs is left for future investigation.

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Shearwater Foundation announces latest Holography Grants

At the end of last year, the Shearwater Foundation announced that its Board of Directors awarded $98,500 in grants through its Holography Program. The Shearwater Foundation Holography Program provides funding to institutions and associations that contribute to the understanding and appreciation of art holography world-wide. The Foundation also recognises individual creative excellence within the field by providing an annual Holography Award.

The MIT Museum, of Cambridge, MA, USA, received a grant of $10,000 as matching funding for an archive project in their holography collection. This will enable them to complete their inventory, establish an accurate and up-to-date database for holograms in the collection as well as photographic images and videos relating to the works.

Urs Fries, Cologne, Germany received $16,500 towards the upgrade and further development of HoloNet, the web site dedicated to providing information on creative holography and related three-dimensional imaging systems. The service provides a home for a diversity of mini-sites and provides artists with server space to publish their own work and comments.

The Royal Photographic Society Holography Group, Bath, UK, received $2,500. This is the first payment of a two year grant to assist with research and development costs for their forthcoming creative holography conference, and to establish an electronic journal for international distribution on the World Wide Web.

Editorial Arte, of Caracas, Venezuela, received a grant of $4,000 towards the cost of purchasing and distribution of the Spanish/English Book and Catalogue *Ruben Nunez*. This is part of a two year grant that will allow Editorial Arte to make this publication available to a wide international art and media audience. The book documents the work of Venezualen artist/holographer Ruben Nunez from his early kinetic work in the 1950's through his exploration of glass sculpture to his pioneering development of holographic art in the 70's, 80's, and 90's.

Alan Rhody of Sebastopol, California, USA, received a grant of $3,000 towards the cost of recording an oral history of creative holography. This experiment will explore the possibilities of making digitally recorded interviews with key individuals in the field, which will then be published to a global audience via the Internet. The German Society for Holography, Halle, received a second payment of $2,500, as the final part of a two year grant to assist in the production and distribution of their English-German publication *Interferenzen*. This grant will enable them to extend the scope and distribution of the publication and make it available to a wide international audience.

The Center for the Holographic Arts, Long Island City, USA, received their second payment of $50,000 in a three year grant to further assist with the development of the Center's international Artist-in-Residence program. Several artists were selected from open submissions to receive an A-I-R placement at the Center. Studio time, materials, access to equipment—as well as technical and aesthetic support—were provided: this resulting in the production of new works. These new pieces have been exhibited at the Long Island Center as well as being included in a number of international exhibitions. There are plans by the directors of the Center, Ana Nicholson and Dan Schweitzer, to arrange travelling exhibitions of the work to make the results of the A-I-R program accessible to a wider public.

The 1999 Shearwater Foundation Holography Award was presented to Susan Cowles-Dumitru, New York, USA, in recognition of her outstanding contribution to the field of creative holography. The British-born artist, who now lives and works in the States, received a cheque for $10,000.

The Directors of the Board are delighted to honour artists of outstanding talent and in doing so provide recognition for this developing medium. Nominations for the Holography Award were provided, as in previous years, by a confidential group of international advisors selected by the Foundation for their expertise in the field.

On a final note, the Directors of the Board are pleased to announce that a new, provisional, category for grant applications is to be established in 2000. Registered museums and public galleries will be able to apply for a grant towards the purchase of creative holography for their collections. Full details of this new category can be found on the Foundation's Web site (see address below) or by contacting the program director at the above address.

The Shearwater Foundation does not accept applications for its Holography Award program. Nor does it accept unsolicited résumés, slides or proposals, publications or subscriptions. The Foundation does not fund projects outside of its stated areas of interest.

For further information, grant guidelines and application procedures please visit:
http://www.holonet.khm.de/Shearwater
Or contact:
The Director
Shearwater Foundation Holography Program
46 Crosby Road, West Bridgford
Nottingham NG2 5GH, UK.

Benyon makes New Year Honors List

The year 2000 began with state recognition for British holographic artist Margaret Benyon, whose name appeared in the New Year Honors List. She was awarded an MBE for her services to art by Her Majesty the Queen in an investiture ceremony that took place at Buckingham Palace on 22 February. This appointment should help to raise the profile of the field in general and, says Benyon, would not have been possible without the support of friends and colleagues.

The award is a state decoration (or medal) that Britain, in common with many other European nations, awards to its citizens in recognition of their contribution to the nation. In this millennium honors list, for instance, Richard Branson, head of Virgin, was knighted (becoming Sir Richard Branson). There are a number of different awards made, CBE, OBE and MBE among them, all of which belong to the Order of the British Empire.

Holographic Optical Telescope and Scanner (HOTS) for lidar applications

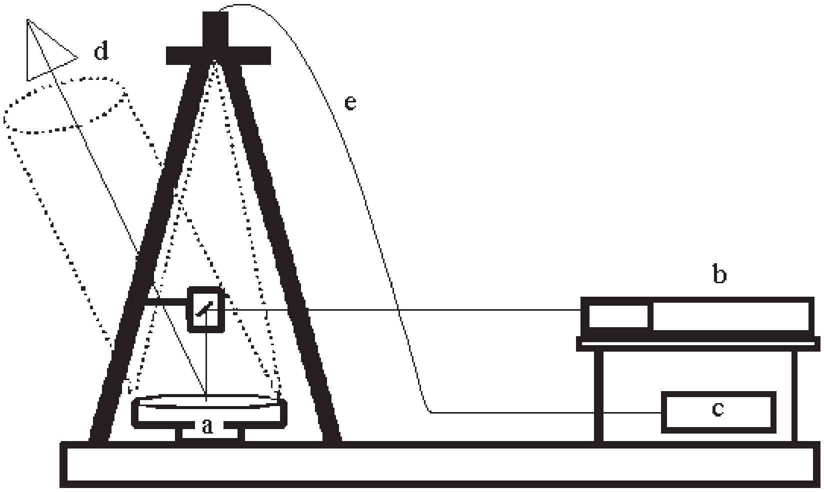

Figure 1. The PHASERS system shown includes: (a) an HOE, (b) a laser transmitter with frequency doubler, (c) a PMT photon counting detector, (d) the field of view of the HOE, and (e) a fiber optic delivery system.

We are currently testing and developing holographic optical telescopes and scanners (HOTS) for lidar (light detection and ranging) applications.[1] This technology provides an alternative to conventional large aperture scanning receivers employed to measure atmospheric wind, humidity, temperature, pressure, cloud, and aerosol profiles. Current lidar receiver technology uses large reflecting telescopes, which must be rotated to implement scanning of their narrow field of view (FOV), or they use a large flat mirror in front of the telescope to perform the scanning. Focal-plane scanning approaches are not viable, because they require a large FOV, which admits too much background to permit daytime operation. Thus, for air- or spaceborne applications, present technologies require a substantial portion of the instrument size and weight budget to be dedicated to the receiver and associated stabilization apparatus to counter the scanner's angular momentum.

Figure 2. Photograph of HARLIE (black boxes), at Utah State University, during a ground-based field campaign.

In contrast, HOTS are built around one or more holographic optical elements (HOE), each of which is a thin film with an index modulated diffraction pattern throughout its volume. These volume phase holograms[2] are produced by exposing a glass plate, coated with a film of dichromated gelatin emulsion, to two or more mutually-coherent laser beams. The object beam emanates from a pinhole, producing spherical wavefronts, while a second, planewave beam serves as the reference, interfering with the object beam in the gelatin. The angle between the beams at the plate determines the diffraction angle during reconstruction. In the lidar application, laser light scattered off atmospheric constituents acts as the reconstruction beam. The scan capability of HOTS is accomplished by rotating the HOE in its own plane. In this configuration, the outgoing laser beam is directed in a conical scan off the HOE, while the backscattered laser light is simultaneously collected by the HOE and focused onto a fixed detector package. Being diffractive elements, HOEs also provide primary spectral filtering for background light rejection. This simple device combines scanning, collecting, and filtering into one optic, which reduces the complexity, overall mass, and cost of the entire lidar system in which it is used.

There are currently two lidar systems that utilize the HOTS technology. Both systems employ HOEs produced by Ralcon, Inc. of Paradise, Utah. The ground-based test facility for reflection HOEs is the Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS),[3] which is located on the campus of Saint Anselm College. This system, depicted in Figure 1, has been operated over the past seven years to successfully obtain conical atmospheric aerosol profiles. The PHASERS system is built around a 40cm volume phase reflection HOE centered at 532nm (the second harmonic of Nd:YAG lasers). The HOE has a 1.2mrad field of view that makes an angle of 48° relative to the plane of the thin film. Therefore, when rotated, the HOE sweeps out a 84° (full angle) cone centered on the zenith. The fixed data system uses a fiber optic located at the focus of the HOE to deliver the backscattered radiation through a filter set, onto a photon-counting photomultiplier tube, which is connected to a multichannel scaler.

The Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE), shown in Figure 2, is an aerosol lidar based on a 40cm transmission HOE that works at the Nd:YAG fundamental wavelength of 1064nm. Operated by the Laboratory for Atmospheres at NASA-Goddard Space Flight Center (GSFC), HARLIE was flown in a series of short test flights in the spring of 1998.[4] The system has also been operated in several ground-based experiments using a dolly that was made to allow it to be held in any of eight positions spaced 45° apart. For ground based measurements, it is normally used with the rotation axis pointing to the zenith, with the HOE sweeping out a 90° (full angle) cone where the FOV is always at a 45° elevation. With the axis tilted at 45°, the scan will sweep out a cone with one edge on the horizontal and another on the vertical. HARLIE uses a 2mJ, 5kHz pulsed YAG with a single Geiger-mode avalanche photodiode detector. It has two ping-ponged scalar units to avoid any dead-time due to data readout. Together PHASERS and HARLIE represent the first successful deemployment of the HOTS

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Pulsed digital holography for the 3D measurement of vibrating objects

Digital holographic interferometry has been established as a readily available technique for the measurement of surface deformations and for shape determination.[1-3] The method returns images containing the deformation of a surface as a continuous function. In the past ten years, those working with laser-based techniques have devoted a lot of attention to the combination of three-dimensional deformation measurements needed to capture all the 3D information about objects undergoing any type of deformation. Today, these laser systems use high-resolution CCD cameras, replacing wet processing and film with electronic and digital processing.

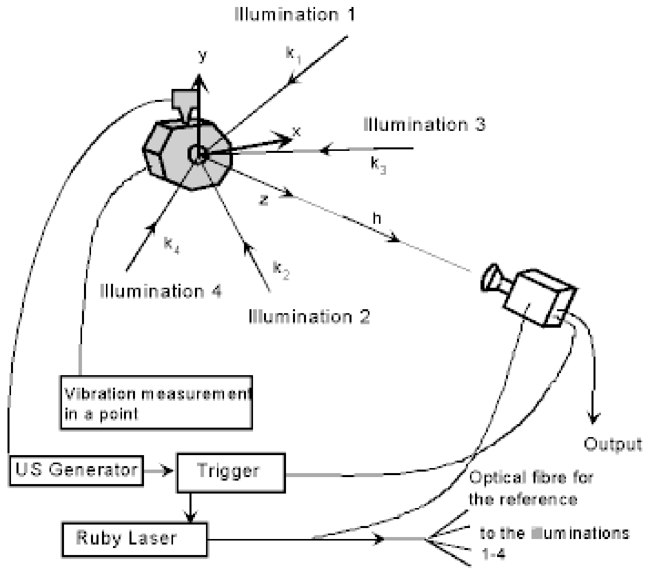

Figure 1. Setup for 3D recording.

Our pulsed digital holography system allows us to acquire data in order to get quantitative information about the 3D deformation of a vibrating object. Figure 1 shows, schematically, the experimental setup. Light from a pulsed ruby laser is divided in two beams: one is coupled into an optical monomode fiber and serves as the reference beam, and the other is divided into four beams used to illuminate the object from four different directions (k_1-k_4). The digital holograms (created by interference between the object and reference beams) are recorded individually for each illumination direction. This process is done for the two laser pulses emitted by the ruby laser, and two digital holograms are captured on separate frames of the CCD camera. The method for recording two separated holograms with two pulses of the ruby laser separated by few microseconds is described in References 1-2.

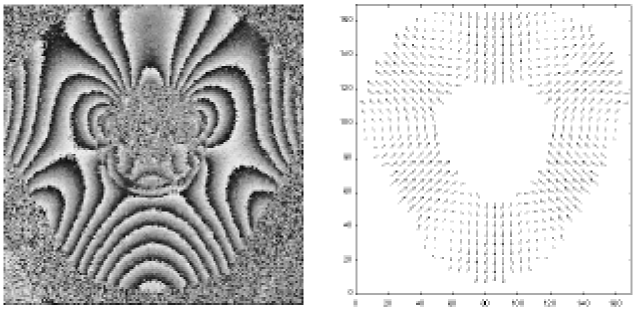

Figure 2. 3D measurement of a tool for metal forming vibrating at 21.5kHz. (a) Fringe phase map obtained from illumination direction 4. (b) direction of the in-plane deformation of the vibrating test object. The scale shows the size of the object in millimeters.

Digital reconstruction of the recorded holograms allows the direct determination of the optical phase. By subtraction of the phases recorded between the two pulses, we get a phase map containing the information about deformation. For the absolute measurement of a vibration using holography, it is necessary to have a reference point where the absolute vibration is known. This is due to the fact that, in pulsed holography, we measure the relative deformation between two pulses fired at different times. A precise 3D measurement of the vibrations at a point is performed by using a 3D laser Doppler vibrometer. In the evaluation procedure, the phase data obtained from the four illumination directions is combined with the point measurement data to obtain the true deformation of the object along the three spatial directions *(x, y ,and z).* It is, in particular, possible to separate out the vibration in the components that are tangential and normal to the object surface.

Figure 2 shows experimental results from an object vibrating at 21.5kHz (low frequency ultrasound). This object is a special tool used in the metal forming processes and is influenced by ultrasonic waves. The fringe phase map in Figure 2 (a) shows an example of a phase map obtained for the determination of the 3D vibration (taken in the illumination direction).[4] The deformation between each fringe corresponds to half the wavelength of the laser light used (694nm). Figure 2 (b) shows the direction of the vibration in the plane of the object. In this case of a planar object, the in-plane and out-of-plane vibration components can be directly separated. However, in the case of a curved object, the shape of the object is also required for such a separation. The shape can be measured using the same ruby laser in the same experimental arrangment.[3] Using our pulsed digital holography system, it is thus possible to obtain all necessary data for the determination of the shape of arbitrarily-shaped objects and their 3D deformation.

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Imaging bypass system with correction for primary mirror distortions

Holography provides an efficient tool for the correction of phase distortions, introduced by some optical path or element. So, in the early 1970s, it was proposed that holographic correction be applied to optical telescopes.[1,2] The distortions of the telescope's primary mirror (PM) could be read out by a beam of coherent radiation sent to the mirror surface from its center of curvature, and then recording the hologram of these distortions. The processed hologram could then be mounted in the focal unit (eye-piece) of the telescope. Illuminated by a beam coming from a remote imaged object and distorted by the PM, this hologram reconstructs the non- distorted wave. As long as the field of telescope vision and spectral range are limited, such reconstructions can be done using the incoherent radiation, and thus the distortions are corrected. The feasibility of this method was confirmed in several experiments but, at the time, it did not find the real practical application due to its lack of ability to cope with dynamic distortions.

However, the idea has been revived in the last few years. This new interest has been due, first of all, to the recent progress in the field of dynamic holography, where the hologram can be used as a real-time device. So-called bypass (non-reciprocal) optical telescopes and beam directors, along with various design methods, have also been developed.[3,4] These systems were intended to apply phase conjugation techniques to compensate for the telescope PM. A coherent beam of light would read out the distortions from the center of the PM curvature, after which it was phase-conjugated and sent to the PM, but now from its focus. Again the distortions were compensated for.

The basic idea behind these bypass optical systems can be also applied to the task of dynamic holographic correction. Recently several papers have been published where such a system has been realized using dynamic holograms, recorded in thermal media,[5] photorefractive crystals[6] and optically-addressed liquid-crystal spatial light modulators (OA LC SLM).[7,8] The latter elements have proved themselves to be especially interesting for dynamic holographic correction in incoherent radiation. See, for example, Reference 9: here a plain (thin) dynamic hologram, free of angular and spectral selectivity, was recorded. This allowed both the telescope's field of corrected vision and spectral range to be significantly enlarged. The way this worked was that two waves, recording the hologram, illuminated the OA LC SLM photoconductor layer.[10] Photoinduced charge carriers stored on the boundary between the photoconductor and LC modify the LC refraction index. With the use of relatively weak (some 10^{-4}-10^{-6} W/cm^{2}) beams of coherent radiation, therefore, plain dynamic holograms with very high diffraction efficiency (up to 30-35%, the theoretical limit for plain holograms)[11] can be formed, with a sufficiently short hologram renewal time (10^{-1} to 10^{-3}sec).

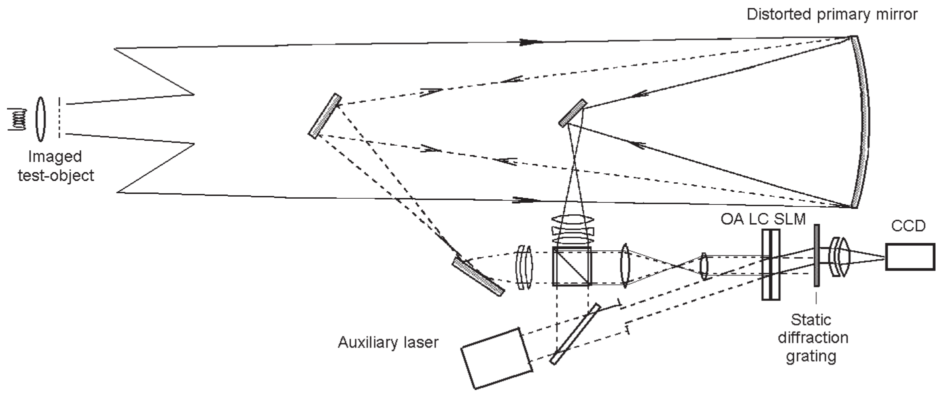

Figure 1. Schematic of the experimental setup

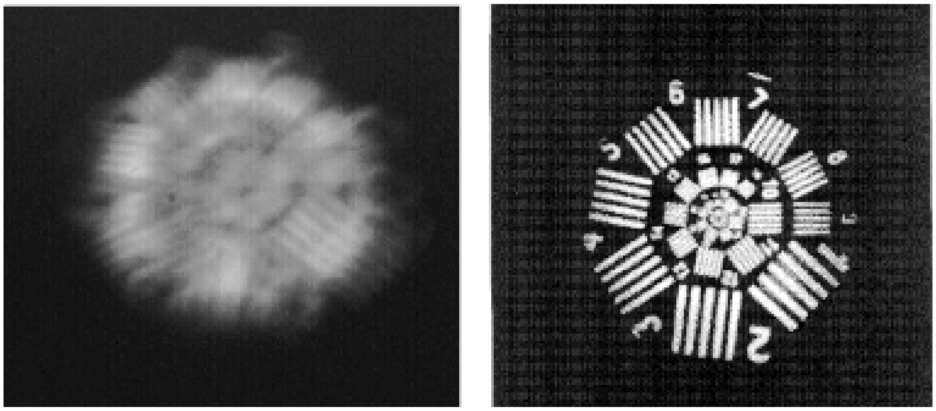

Figure 2. Distorted (left) and corrected (right) images of standard test chart.

Recently, we built an experimental system of this kind which has what we believe to be the fastest numerical aperture yet. Our experimental setup is shown in Figure 1. The laboratory model of the telescope, with a magnification of 1:10, was based on a PM with a diameter of 300mm and focal length of 1200mm (D:F=1:4). Three different (replaceable) primaries were used in the experiment:

1. A thin, poor-quality mirror with randomly distributed 2-3µm deformations of its surface;
2. A segmented mirror, whose six segments had random relative piston shifts with magnitudes of up to 2-3µm;
3. And, for comparison purposes, a high-optical-quality mirror.

The beam from the second-harmonic Q-switched Nd:YAG laser (λ=0.54 µm) passed through the special three-component lens[12,13] and read out the distortions of the PM. Then it was re-collimated by the same lens and interfered with the plain reference wave. The interference pattern illuminated the photoconductor layer of the transparent OA LC SLM element, mounted in the plane where the lens imaged the pupil of the PM. The dynamic hologram of the distortions was thus recorded. The spatial carrier was 95 lines per millimeter.

The telescope imaged a standard test-chart, positioned 17m from the PM. The design field of system vision was 1cm. The imaging was done in the light of a conventional tungsten lamp. Light from the imaged object was collected by the PM and collimated by a special two-component lens system,[12,13] and a beam-

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High-efficiency silver-halide-sensitized gelatin holograms in Slavich emulsion

Agfa silver-halide-emulsion plates have been very highly regarded for a number of years, and have been successfully used in display holography and holographic optical elements (HOEs). As a result, when in 1997 Agfa-Gevaert stopped producing their widely used holographic materials 8E75 HD and 8E56 HD, it represented a serious problem for many holographers.[1] Since then, many have been working to design and study alternative silver-halide materials which could fill the gap: in particular, currently-available materials such as those of Slavich (Russia), the Royal Holographic Art Gallery (Canada) and the BB series from Holographic Recording Technologies (Germany) have been under some scrutiny. With many other people, we have been carrying out trials to determine which of these new and unfamiliar silver-halide materials make for the highest quality holograms. In particular, our focus has been on making HOEs.

Two useful ways of recording HOEs as phase holograms involve using dichromated gelatin (DCG), and bleached emulsions. A hybrid method is silver-halide-sensitized gelatin (SHSG). This method improves the performance of DCG (spectral and energetic sensitivities) while retaining similar diffraction efficiencies and noise levels.

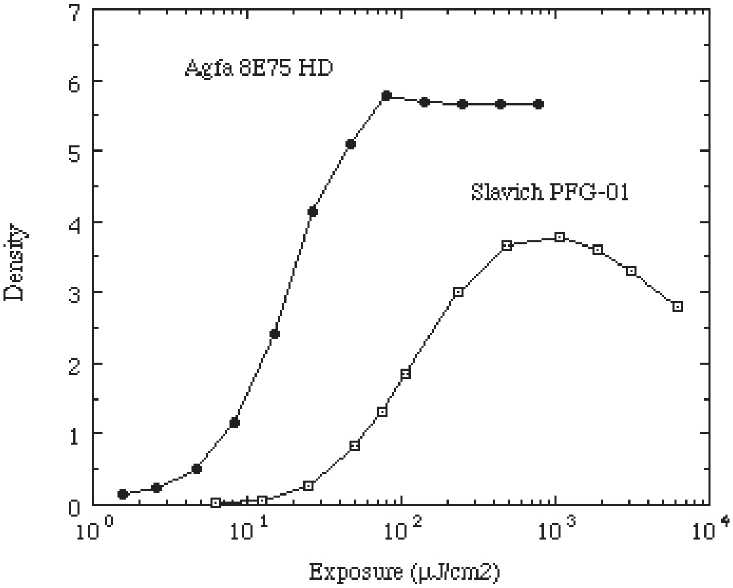

Figure 1. D-logE curves for PFG-01 and Agfa 8E75 HD emulsions with D-19 developer.

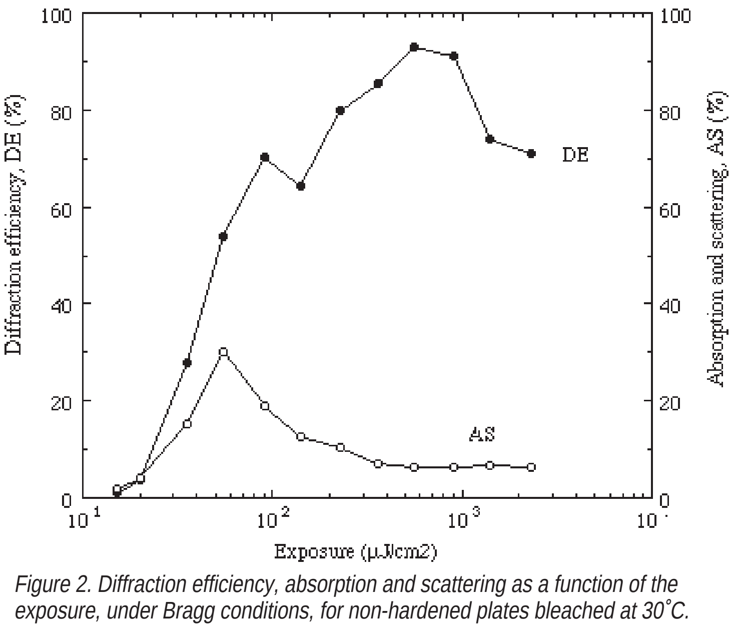

Figure 2. Diffraction efficiency, absorption and scattering as a function of the exposure, under Bragg conditions, for non-hardened plates bleached at 30˚C.

In our lab we have studied the applicability of the SHSG technique to one of the newly available silver-halide materials, the PFG-01 emulsion from the Slavich company. Despite the fact that Slavich PFG-01 emulsions are presented as being equivalent to Agfa 8E75 HD emulsions, we have found some important differences between them. For example, the gelatin of PFG-01 emulsions is softer than that of the Agfa emulsions. The size of the silver halide grains suspended in the gelatin of PFG-01 emulsion is similar to that of Agfa 8E75 HD, ~40 nm, and the spectral sensitivity is in the 600-680nm range. Figure 1 shows the D-log E curves for PFG-01 and Agfa 8E75 HD plates, when Kodak D-19 developer is used. It can be seen from the figure that the energetic sensitivity of PFG-01 plates is lower than that of Agfa 8E75 HD, and that a lower maximum density is obtained when using PFG-01 plates.

To study the efficiency of using PFG-01 plates in the SHSG technique, we recorded unslanted transmission gratings by using two collimated beams from a 15mW He-Ne laser (633nm). The two beams, of equal intensity, hit the emulsion to form an angle (in air) of 45˚. The spatial frequency of the gratings was calculated as 1200 lines/mm. The exposed plates were processed according to a modified version of the optimized SHSG procedure in Reference 2. Since the PFG-01 gelatin is very soft, a number of trials were carried out on Slavich PFG-01 plates in order to optimize the SHSG procedure, taking into account the degree of hardening of their gelatin component.[3]

The best results were obtained when: a) the plates were hardened by means of a Formalin bath and bleached at 50˚C; and b) when the plates were not hardened, and with the bleach bath temperature maintained at 30˚C.

Figure 2 shows the diffraction efficiency and the absorption and scattering as a function of the exposure for non-hardened PFG-01 plates bleached at a temperature of 30˚ C. As can be seen, a high maximum diffraction efficiency of 93% was achieved, and the total losses caused by absorption and scatter were lower than 10%. These results proved to be better than those obtained with the Agfa 8E75 HD plates, confirming the application of SHSG derived from PFG-01 plates for recording high quality transmission holograms. These results also show that PFG-01 emulsions are not only an alternative to Agfa 8E75 HD plates for recording SHSG holograms, but also that even better results can be obtained using this new material.

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Three-color laser

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not be operated more than once a minute, so the power unit could minimized by taking advantage of capacitor batteries' small charge current. Also, due to the low repetition frequency of the basic channel of amplification, the cooling system for the setup is considerably simpler.

Two-cascade Stimulated Brillouin Scattering mirror

To maintain the second pass of radiation through the basic channel of amplification, a Stimulated Brillouin Scattering mirror induced in the amplifiers—which also serves to compensate for phase distortions—has been used. To increase the reflection coefficient, it was preferable to use a two-cascade scheme consisting of two cuvettes with tetrachloride of carbon or titanium. A focusing lens and neutral density filter is located between these two in order to optimize wavefront parameters. The use of a Stimulated Brillouin Scattering mirror ensures the required smooth intensity distribution at the input to the nonlinear frequency converter. By using relatively large numbers of amplifiers and taking measures to improve the beam quality, we obtained an output energy of about 20J in a single pulse.

Nonlinear frequency doubler in KDP

After the second pass through the basic cascade of amplification, the light is directed to a nonlinear crystal (KDP) through polarization isolation. This is where effective, second-harmonic generation takes place. Because of the smooth structure of the beam, high radiation intensity, diffraction divergence, and the optimization of the length of the nonlinear crystal, the efficiency of conversion into the second harmonic was about 65%. As a result, the output was about 13J of radiation at 531nm.

Frequency adder in KDP

Both the second harmonic and basic frequency are next delivered to a nonlinear frequency adder in KDP. Here, the third harmonic of the neodymium laser radiation (at 351 nm) is generated with up to 40% efficiency based on the total input energy (resulting in an output of 8J). Reduction of efficiency, and thus the output energy of the third harmonic, is carried out by rotating the crystal around the axis of input radiation, or by selecting the appropriate crystal length.

Compressed hydrogen cuvette for Stimulated Raman Scattering

To obtain red and blue, we have used Stimulated Raman Scattering (SRS). For this purpose, the residual after the frequency-adder radiation of the second and third harmonics are focused into cuvettes with hydrogen compressed up to 100 atmospheres (for generation of the first anti-Stokes component). The choice of hydrogen as an active media provided the maximal frequency shift and generation of radiation on a wavelength of 670nm and 411 nm.

By varying parameters of frequency doubling and addition, and also of the SRS process, it was possible to redistribute the output energy between colors over a wide range. Since the starting point for the radiation of all frequencies was the master oscillator, the differently-colored beams from the laser system are all automatically synchronized.

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Holographic Optical Telescope

continued from p. 5

technology in ground-based and airborne lidar systems, respectively.

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Holographic imaging

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Kirchhof Helmholtz transform, according to the procedure suggested by Kreuzer et al.[4] Figure 2c shows the reconstructed wavefront in a 60nm×60nm sheet in the plane of the object. The outline of a rod-like strand with a diameter of ~2nm can be recognized, in agreement with expectations, for a single PcPS molecule.

Via a systematic variation of molecular objects and imaging parameters (size of the source, electron energy, distance between source and object) researchers now need to optimize the operational parameters of the LEEPS microscope. This way, point source holography can eventually mature into a tool for the investigation of macromolecular structural properties. Simulations have shown that, under certain conditions, the resolution of intramolecular features <1nm should be feasible.[4] Applications of LEEPS microscopy could lay within the efforts to understand the structure of biological macromolecules. Of the $\sim 10^5$ different proteins that are found in the human body, only ~1000 have been crystallized and solved by x-ray crystallography.[5] For those that have not been crystallized, although the amino-acid sequence may be known, the conformation of the molecule is not. Thus, there is an need for methods capable of imaging individual macromolecules without crystallization. LEEPS can potentially contribute to this field. Besides the investigation of biomaterials, coherent, low-energy electrons from point sources are also sensitive probes for electrical and magnetic properties of matter. Thus, point source imaging is a new and challenging field with numerous unexplored applications.

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Imaging bypass

continued from p. 7

splitting cube combined the two beams. The plane of the dynamic hologram corresponded to the plane where the two-component lens imaged the pupil of the PM. The scale of this image was the same as that produced by the three-component lens of the other branch. After diffracting through the dynamic hologram, the PM distortions were subtracted (corrected) in the minus first order of diffraction. The dynamic hologram expanded the radiation from the object into its spectrum, and the spectral components were recombined[2] by the auxiliary static diffraction grating with the same spatial frequency.

The image of the object was recorded by the CCD-camera. It was compared with the image recorded in the zeroth order of diffraction, i.e. without correction. In Figure 2 (left) is shown the severely distorted image of the test object with the thin, poor-quality PM. One can see that it is practically unresolvable. Approximately the same image quality was observed with the use of segmented PM.

The use of a dynamic holographic corrector resulted in practically total elimination of the distortions in a sufficiently wide spectral band. We have analyzed the dependence of the image contrast vs. spatial frequency of the chart. The image quality with all three PMs was practically one and the same, and was nearly at the diffraction limit. In Figure 2 (right) one can see the corrected image, recorded with the same PM as shown on the left. This image was recorded using a colored filter (bandwidth 50nm, centered at the recording wavelength of 540nm).

Our results, and the results of other teams,[5-7] open up the possibility of creating a new generation of space telescopes and other optical systems. Now we can obtain diffraction-limited performance with the use of very poor quality, and thus very lightweight (maybe even inflatable) and cheap primary mirrors, that can nonetheless be extremely large. These systems can be also used for applications that require laser emission with very low divergence.

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Holography

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Holographic imaging of single macromolecules with low-energy electron point sources

Holographic imaging with coherent, low-energy electrons from point sources (LEEPS) is a novel method for characterizing single molecules. The electron point source is realized by a sharp metal tip with a radius in atomic dimensions that is made by field-emission/field-ion techniques.[1] The source is placed close (~100 nm) to a thin molecular object, ideally a single molecule, and a voltage of 20-200V, sufficient for electron emission, is applied. A part of the electron's wave function is then scattered by the object and interferes with the unscattered part, so that an in-line hologram is generated from which one can reconstruct the object's structure (see Figure 1).

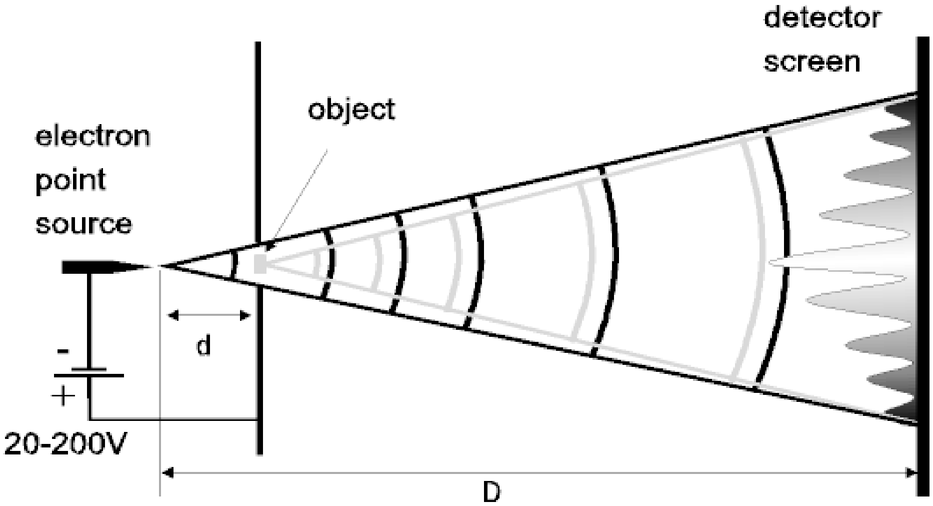

Figure 1. Schematics of the LEEPS microscope.

LEEPS microscopy was first demonstrated at IBM Zürich in 1990. Fink and co-workers[2] built an electron projection microscope in which the relative motion between the source and object could be performed with nanometer precision. By approaching the source to the object, magnifications (M=D/d) of $\sim 10^6$ can be obtained, and the projection image evolves into a hologram that is detected by a channel-plate/phosphor screen assembly.

At the Universität Heidelberg (Germany), we work on the experimental foundations of LEEPS microscopy, the building and improvement of microscopes, as well as the development of strategies for the preparation and identification of macromolecular entities.[3] As in transmission electron microscopy, sample preparation is a challenging task. The mean free path of low-energy electrons in solids is only a few nanometers. Thus, a molecular object cannot be placed on a solid sample support, which is opaque for electrons in this energy range. However, holey support structures have proved to be useful, as macromolecules occasionally 'bridge' some of the holes. By having the source approach such an opening, the molecule is exposed to the electron wave and imaged, while unwanted interactions between the electrons and support structure are minimized.

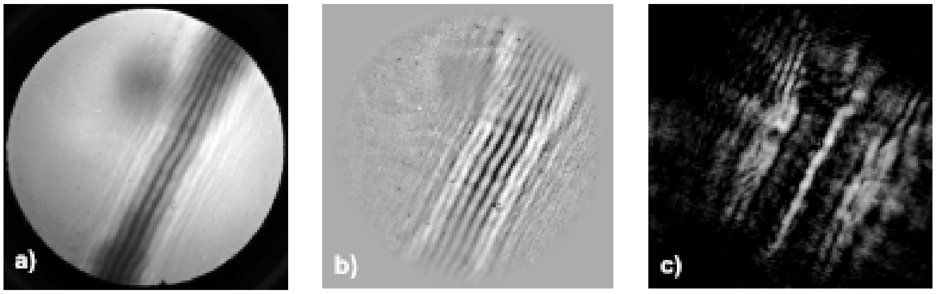

Figure 2. (a) Hologram of a single PcPS molecule. The distance between the source and the molecule is ~200 nm. (b) "Contrast image," i. e. the hologram after numeric removal of the background due the emission characteristics of the source and discontinuities of the electron detector. (c) Reconstruction of the wavefront in a 60nm×60nm sheet in the plane of the object. The intensity distribution shows the outline of a rod-like PcPS molecule with a diameter of 2nm.

Figure 2 (a) shows a hologram of a single polymeric macromolecule (phthalocyanato polysiloxane, PcPS) that was recorded with the Heidelberg LEEPS microscope.[3] The molecule was spanned through a hole in a microfabricated silicon membrane. The source is placed 200nm from the molecule and emits electrons of 71eV (wavelength, 1.45Å). An interference pattern is clearly visible. This hologram is then further processed and the background, originating from the anisotropic emission characteristic of the source as well as discontinuous contrast features from the boundaries of the electron detector and the CCD, are removed (see Figure 2 (b)). To reconstruct this "contrast image" we applied a

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