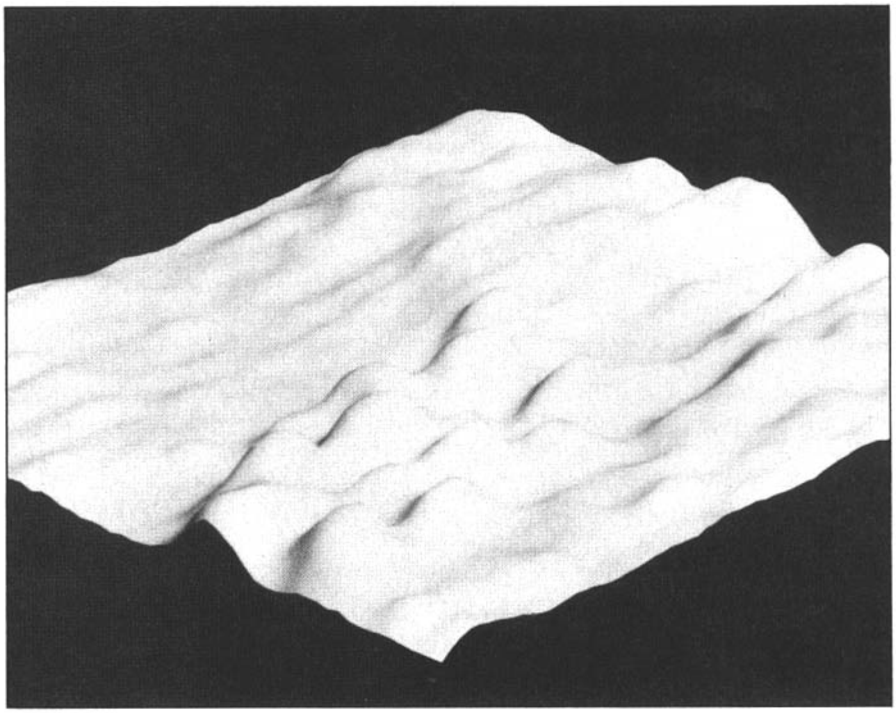
Holographic display of scanning tunneling microscopy images

By Dror Sarid

In a joint venture, the Optical Sciences Center, University of Arizona, and the Spatial Imaging Group, Massachusetts Institute of Technology, have produced the first hologram showing images of single atoms. The original image of a structure having atomic resolution was obtained at the Optical Sciences Center using scanning tunneling techniques. A diskette containing the digitized image was sent to the MIT group, which converted it into an achromatic holographic stereogram.



Achromatic holographic stereogram of two attached six-membered rings of metal atoms on top of a graphite substrate. The image represents an area of approximately 25Å by 25Å.

Scanning tunneling microscopy (STM) is a novel technology that was invented in 1982 by Binnig and Rohrer. It enables one to obtain images of surface structures and local density of states with atomic resolution. The technique utilizes a sharp tip mounted on electronically controlled piezoelectric manipulators, and is brought to within several angstroms distance to a conducting surface. The application of a voltage between the tip and the surface gives rise to a tunneling current which is amplified and recorded. The current depends exponentially on the tip-to-surface distance, and is sensitive to the local density of states.

By raster scanning the tip across the surface one obtains a topographic image of the uppermost atomic layer. By monitoring the derivative of the tunneling current with respect to the applied voltage, as a function of the applied voltage, it is possible to map the local density of states (LDOS), while the polarity of the applied voltage determines whether the LDOS is that of the valence or the conduction band.

STM has been useful for the characterization of semiconductor clusters used for nonlinear applications. These clusters, which have dimensions on the order of 100 Å, exhibit interesting and useful quantum effects arising from the confinement of the charge carriers. The optical response of these clusters is currently being investigated at the Optical Sciences Center by several groups. Optical characterization techniques however,

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U.S. may soon have national optics standards

At long last, the United States is on the verge of having some "national" optical drawing, coating, and testing standards.

In July (as *Optics News* was going to press), balloting was underway to determine whether or not a draft proposal from ISO/TC 172/SC 1—Fundamental Standards should be accepted.

The 130-page document includes three sections on OTF testing, seven on methods of specifying optical components on mechanical drawings, and five on various environmental tests for optical elements.

In a sense, these standards are being forced on the United States, which has never had any truly national optical standards written by non-governmental, standards writing organizations. Through the American National Standards Institute (ANSI), the United States is a member of the International Standards Organization (ISO). When ISO adopts a standard for which there is no comparable standard in a member country, it becomes the *de facto* national standard of that country.

One reason for this country's minimal involvement in the generation of these new international standards has been the past lack of industry support. With the founding of APOMA (the American Precision Optical Manufacturers Association), this situation seems to be changing. Robert H. Leshne of Trans World Optics started APOMA about two years ago as a trade and lobbying organization. Meanwhile, ANSI appointed delegates to the technical committee responsible for developing the international optical standards.

While the new standards appear somewhat complex and "foreign," they will markedly reduce misunderstanding of optical specifications, both domestically and internationally.

Copies of the draft standards are available from OSA. The material is still subject to change and, therefore, should not be referenced in optical drawings. However, reviewing the draft will be valuable preparation for the day when the standards are issued in final form.

—Robert E. Parks

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sample only the average properties of a collection of such clusters whose size distribution is large. Scanning tunneling microscopy, on the other hand, can yield information about the size, atomic structure, or LDOS of the valence and conduction bands of each one of individual cluster.

Atomic images produced by STM are usually displayed as grey scale, topographic, or contour maps, each of which stresses a different point of view. It seemed only natural to extend the number of possible display methods by using holographic techniques.

A suitable method for producing such a hologram entails taking the digitized image, as obtained from the scanning tunneling microscope, and making 100 slides of computer-generated surface topographies that would be observed by a viewer from different directions. In the next step, a recording medium is divided into 100 strips, and a hologram of each slide is individually recorded on its respective strip. Finally, the multiple-image hologram is holographically recorded as a single holographic stereogram. The advantages of this method include: 1) one can use white light to reconstruct the image; 2) a high-resolution plotter or electron beam is not needed; and 3) this is an easy method to reproduce many holograms.

Our computer-generated multiple-view achromatic holographic stereogram shows two attached six-membered rings of metal atoms on top of a graphite substrate, with a distance of approximately 6.5 Å between the centers. The work described here demonstrates the feasibility of observing small structures and recording them holographically. In future work we plan to characterize layered semiconductor clusters fabricated on graphite or gold surfaces.

It seems obvious that the visualization and comprehension of structures that are more complex than the one demonstrated here will be dramatically enhanced by a holographic display. This technique, when combined with other probing techniques, such as scanning force microscopy for example, could be used for displaying metallic, semiconductor, or dielectric structures as well as biological specimens.

The scanning tunneling microscopy was performed at the Optical Sciences Center, University of Arizona, by Dror Sarid's Tip Microsopy Group, with Tammy D. Henson and L. Stephen Bell, Lunar and Planetary Lab. The computer-generated hologram was made at Massachusetts Institute of Technology by Stephen A. Benton's Spatial Imaging Group, with John S. Underkoffler and Michael A. Klug.