and selecting microscopic sharp shards of the material for use as specimens. Each selected shard is oriented with its sharp tip facing away from the tip of a stainless-steel pin and is glued to the tip of the pin by use of silver epoxy. Then the shard is milled by use of a focused ion beam (FIB) to make the shard very thin (relative to its length) and to make its tip sharp enough for atom-probe analysis. The method of sharp shards is extremely time-consuming because the selection of shards must be performed with the help of a microscope, the shards must be positioned on the pins by use of micromanipulators, and the irregularity of size and shape necessitates many hours of FIB milling to sharpen each shard.

In the present method, a flat slab of the material of interest (e.g., a polished sample of rock or a coated semiconductor wafer) is mounted in the sample holder of a dicing saw of the type conventionally used to cut individual integrated circuits out of the wafers on which they are fabricated in batches. A saw blade appropriate to the material of interest is selected. The depth of cut and the distance between successive parallel cuts is made such that what is left after the cuts is a series of thin, parallel ridges on a solid base. Then the workpiece is rotated 90° and the pattern of cuts is repeated, leaving behind a square array of square posts on the solid base.

The posts can be made regular, long, and thin, as required for samples for atom-probe analysis. Because of their small volume and regularity, the amount of FIB-milling time can be much less than that of the method of sharp shards. Individual posts can be broken off for mounting in a manner similar to that of the method of sharp shards. Alternatively, the posts can be left intact on the base and the base can be cut to a small square (e.g., 3 by 3 mm) suitable for mounting in an atom probe of a type capable of accepting multiple-tip specimens. The advantage of multiple-tip specimens is the possibility of analyzing many tips without the time-consuming interchange of specimens.

This work was done by Kim Kuhlman and James Wishard of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Intellectual Assets Office
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: ipgroup@jpl.nasa.gov

Refer to NPO-30667, volume and number of this NASA Tech Briefs *issue, and the page number.*

Inverse Tomo-Lithography for Making Microscopic 3D Parts

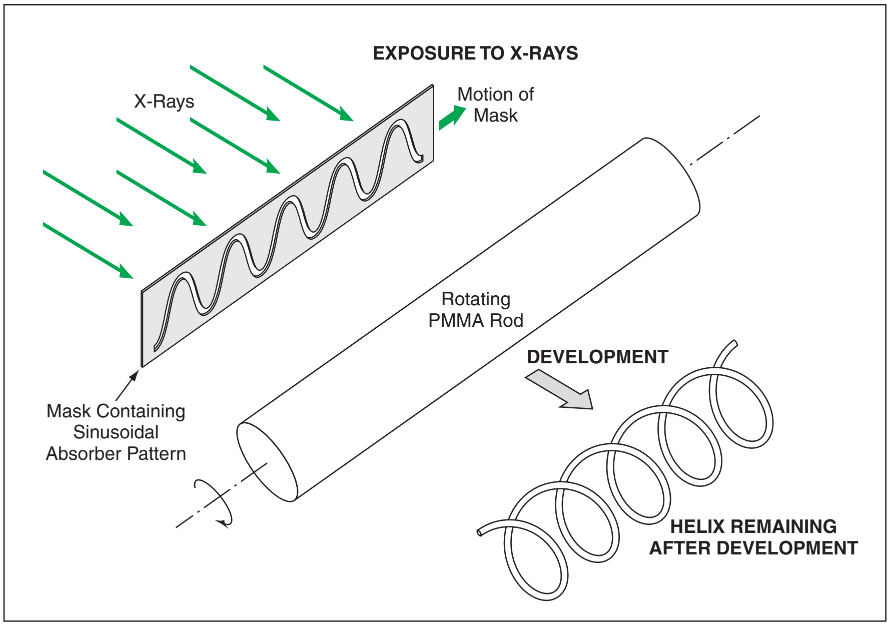
Inverse tomography would be used to generate complex three-dimensional patterns.

NASA's Jet Propulsion Laboratory, Pasadena, California

According to a proposal, basic x-ray lithography would be extended to incorporate a technique, called "inverse tomography," that would enable the fabrication of microscopic three-dimensional (3D) objects. The proposed inverse tomo-lithographic process would make it possible to produce complex shaped, submillimeter-sized parts that would be difficult or impossible to make in any other way. Examples of such shapes or parts include tapered helices, paraboloids with axes of different lengths, and even Archimedean screws that could serve as rotors in microturbines.

The proposed inverse tomo-lithographic process would be based partly on a prior microfabrication process known by the German acronym "LIGA" ("lithographie, galvanoformung, abformung," which means "lithography, electroforming, molding"). In LIGA, one generates a precise, high-aspect ratio pattern by exposing a thick, x-ray-sensitive resist material to an x-ray beam through a mask that contains the pattern. One can electrodeposit metal into the developed resist pattern to form a precise metal part, then dissolve the resist to free the metal. Aspect ratios of 100:1 and patterns into resist thicknesses of several millimeters are possible.

Typically, high-molecular-weight poly (methyl methacrylate) (PMMA) is used as the resist material. PMMA is an excellent resist material in most respects, its major shortcoming being insensitivity. Conventional x-ray sources are not practical for LIGA work, and it is necessary to use a synchrotron as the source. Because syn-



A **Rotating PMMA Rod** would be exposed to collimated x-rays through a mask bearing a sinusoidal absorber pattern while the mask moved along the rod in synchronism with the rotation. Upon development of the PMMA (used here as an x-ray photoresist material), a helix would remain.

chrotron radiation is highly collimated and its wavelength of synchrotron radiation is typically <5 Å, there is very little diffraction and the pattern of a high-contrast mask is projected deep into a resist with nearly perfect vertical sidewalls. Of course, the only three-dimensional shape that can be formed in this way is the locus of points generated by moving the mask pattern along the direction of incidence of the radiation.

In a recently developed variant of LIGA, a rotating PMMA rod is exposed to x-rays through a stationary mask; this technique can be used to make axisymmetric structures; e.g., objects shaped like wine glasses or baseball bats. The proposed technique would also involve stenciling an x-ray image into a rotating PMMA rod, but would differ from prior techniques in that the mask would be moved in synchronism with the rod to generate a three-dimensional pattern. The synchronized motions of the mask and rod would be generated by translation and rotation stages actuated by stepping motors under control by a computer.

Describing the x-ray exposure technique in different words, a changing two-dimensional pattern would be projected into a three-dimensional one. In tomography, one decodes a three-dimensional pattern from the changing two-dimensional pattern obtained by illuminating it from a changing direction. In the proposed technique, one would essentially reverse this decoding process; that is, one would encode or construct a three-dimensional pattern by illuminating the region of interest in a changing two-dimensional pattern: That is why the proposed x-ray exposure technique is called "inverse tomography."

The figure depicts an example of the use of this technique to generate a simple helix. The two-dimensional projection (shadow) of a helix is a sinusoid. To form the helical pattern in a PMMA rod, one would project x-rays perpendicularly toward the rod through a mask with a sinusoidal pattern while rotating the rod and translating the mask along the rod at a speed of one wavelength of the sinusoid per rotation period.

This work was done by Victor White and Dean Wiberg of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-20593