Artifacts for Calibration of Submicron Width Measurements

Dimensional tolerances as small as 1 nm should be possible.

MULTILAYER EPITAXIAL WAFER BEFORE CLEAVING AND ETCHING

WAFER AFTER CLEAVING AND ETCHING
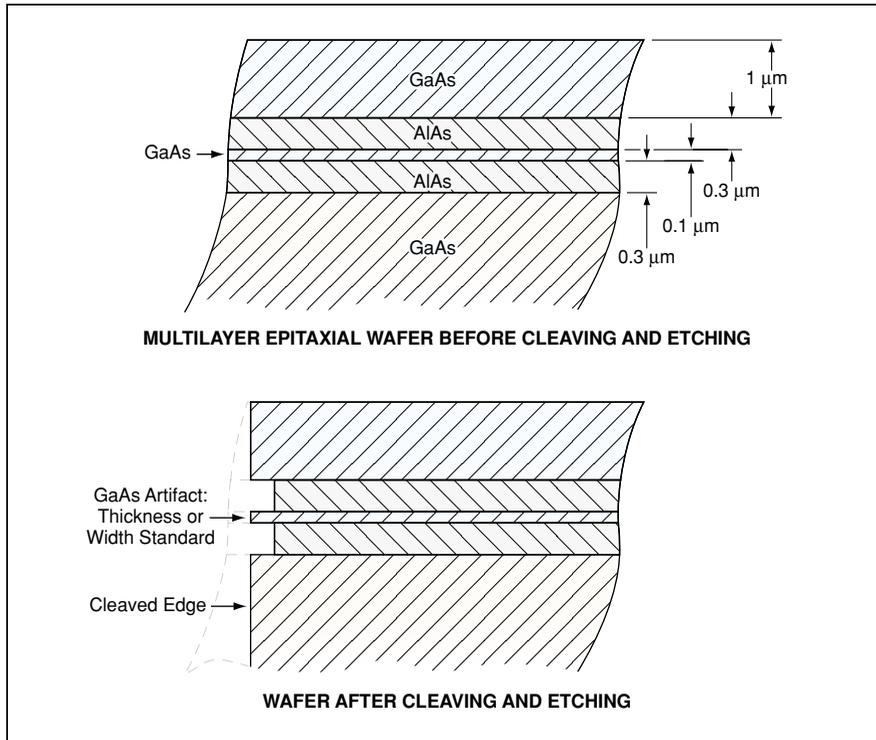
An **Artifact With a Reproducible Thickness of 0.1 μm** is made by MBE of GaAs and AlAs followed by differential etching. The basic concept is not limited to the GaAs/AlAs material system: other semiconductor material systems amenable to MBE and differential etching could be used.

Artifacts that are fabricated with the help of molecular-beam epitaxy (MBE) are undergoing development for use as dimensional calibration standards with submicron widths. Such standards are needed for calibrating instruments (principally, scanning electron microscopes and scanning probe microscopes) for measuring the widths of features in advanced integrated circuits. Dimensional calibration standards fabricated by an older process that involves lithography and etching of trenches in (110) surfaces of single-crystal silicon are gener-

ally reproducible to within dimensional tolerances of about 15 nm. It is anticipated that when the artifacts of the present type are fully developed, their critical dimensions will be reproducible to within 1 nm. These artifacts are expected to find increasing use in the semiconductor-device and integrated-circuit industries as the width tolerances on semiconductor devices shrink to a few nanometers during the next few years.

Unlike in the older process, one does not rely on lithography and etching to define the critical dimensions. Instead, one

relies on the inherent smoothness and flatness of MBE layers deposited under controlled conditions and defines the critical dimensions as the thicknesses of such layers. An artifact of the present type is fabricated in two stages (see figure): In the first stage, a multilayer epitaxial wafer is grown on a very flat substrate. In the second stage, the wafer is cleaved to expose the layers, then the exposed layers are differentially etched (taking advantage of large differences between the etch rates of the different epitaxial layer materials).

The resulting structure includes narrow and well-defined trenches and a shelf with thicknesses determined by the thicknesses of the epitaxial layers from which they were etched. Eventually, it should be possible to add a third fabrication stage in which durable, electronically inert artifacts could be replicated in diamondlike carbon from a master made by MBE and etching as described above.

Navigating a Mobile Robot Across Terrain Using Fuzzy Logic

This strategy is modeled on the actions of a human driver.

A strategy for autonomous navigation of a robotic vehicle across hazardous terrain involves the use of a measure of traversability of terrain within a fuzzy-logic conceptual framework. This navigation strategy requires no *a priori* information about the environment. Fuzzy logic was selected as a basic element of this strategy because it

provides a formal methodology for representing and implementing a human driver's heuristic knowledge and operational experience.

Within a fuzzy-logic framework, the attributes of human reasoning and decision-making can be formulated by simple IF (antecedent), THEN (consequent) rules

coupled with easily understandable and natural linguistic representations. The linguistic values in the rule antecedents convey the imprecision associated with measurements taken by sensors onboard a mobile robot, while the linguistic values in the rule consequents represent the vagueness inherent in the reasoning processes to

generate the control actions. The operational strategies of the human expert driver can be transferred, via fuzzy logic, to a robot-navigation strategy in the form of a set of simple conditional statements composed of linguistic variables. These linguistic variables are defined by fuzzy sets in accordance with user-defined membership functions. The main advantages of a fuzzy navigation strategy lie in the ability to extract heuristic rules from human experience and to obviate the need for an analytical model of the robot navigation process.

The basic building block of the present navigation strategy is a behavior, defined here as a representation of a specific sequence of actions aimed at attaining a given desired objective. Each behavior comprises a set of fuzzy-logic rules of the form

IF C, THEN A,

where the condition C is composed of fuzzy input variables and fuzzy connectives (AND, OR, NOT), and the action A is a fuzzy output variable. Such an IF, THEN rule represents a typical rule in a set of natural linguistic rules that express the actions taken by an expert human driver based on the prevalent conditions. The output of each behavior describable by such a rule set is a recommendation over all possible control actions from the perspective of attaining the objective.

Multiple behaviors, each aimed at one specific goal, can be active simultaneously in the navigation strategy. Blending of multiple behaviors is implemented by combining the outputs (recommendations) of all the behaviors using gain rules of the form

IF S, THEN K,

where S is a logical statement that describes a physical situation, and K represents a fuzzy expression of the gains with which the recommendation of the individual behaviors are weighted in the prevalent situation. The result of the weighted combination of recommendations is then issued as a command to the wheel actuators of the mobile robot.
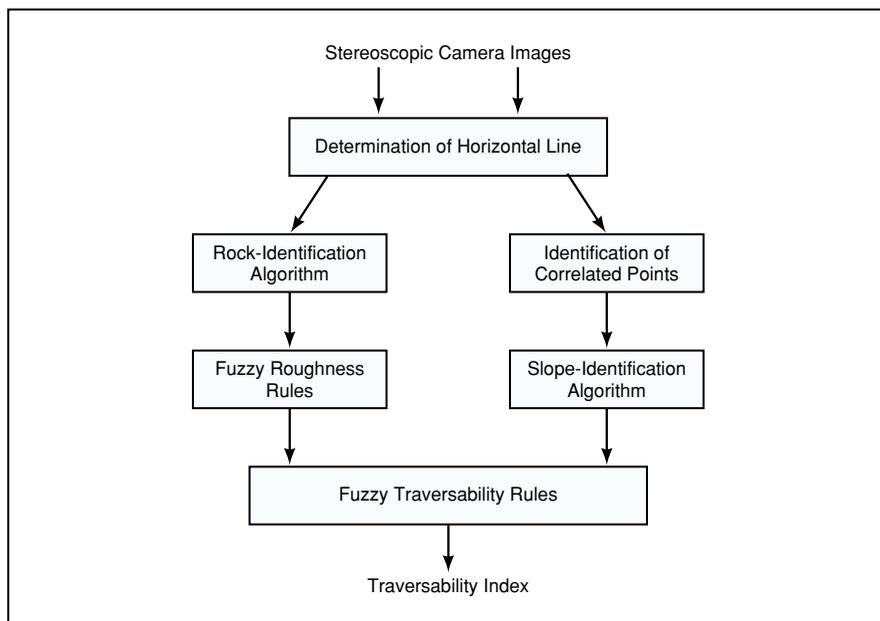
Image Data Acquired by Onboard Stereoscopic Cameras is processed into terrain-quality information and summarized in a fuzzy traversability index.

The present robot-navigation strategy involves three such behaviors, denoted seek-goal, traverse-terrain, and avoid-obstacle:

- The navigation rules for the seek-goal behavior utilize the global information about the goal position to generate the steering and speed commands that drive the robot to the designated destination.
- The navigation rules for the traverse-terrain behavior utilize regional information about the quality of the terrain to produce steering and speed commands that guide the robot toward the safest and the most traversable terrain. The regional terrain-quality information is generated from readings of onboard sensors by use of a set of fuzzy-logic rules. This behavior constitutes a major novel aspect of the present strategy (see figure).
- The navigation rules for the avoid-obstacle behavior employ local infor-

mation about obstacles en route to develop steering and speed commands to maneuver the robot around the obstacles.

The recommendations of these three behaviors are blended through gains or weighting factors to generate the final steering and speed commands to be executed by the wheel actuators of the robot. The gains are also generated by fuzzy-logic rules that take into account the current status of the robot.

This work was done by Homayoun Seraji, Ayanna Howard, and Bruce Bon of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP [see page 1].*

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Designing Facilities for Collaborative Operations

A methodology is emerging from efforts to design a mission operations facility.

NASA's Jet Propulsion Laboratory, Pasadena, California

A methodology for designing operational facilities for collaboration by multiple experts has begun to take shape as an outgrowth of a project to design such facilities for scientific operations of the planned 2003 Mars Exploration Rover (MER) mission. The methodology could also be applicable to the design of military "situation rooms" and other facilities for terrestrial missions.

It was recognized in this project that modern mission operations depend heavily upon the collaborative use of computers. It was further recognized that tests have shown that layout of a facility exerts a dramatic effect on the efficiency and endurance of the operations staff. The facility designs (for example, see figure) and the methodology

developed during the project reflect this recognition.

One element of the methodology is a metric, called effective capacity, that was created for use in evaluating proposed MER operational facilities and may also be useful for evaluating other collaboration spaces, including meeting rooms and military situation rooms. The effective capacity of a facili-