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## Sensor for Monitoring Nanodevice-Fabrication Plasmas

Temperature and trace amounts of chemical species could be measured *in situ*.

Ames Research Center, Moffett Field, California

The term “plasma process diagnostics” (PPD) refers to a spectroscopic technique and sensing hardware that have been proposed for monitoring plasma processes used to fabricate electronic devices that feature sizes as small as several nanometers. Nanometer dimensions are characteristic of the quantum level of miniaturization, where single impurity atoms or molecules can drastically change the local properties of the nanostructures. Such changes may be purposely used in nanoscale design but may also be extremely damaging or cause improper operation of the fabricated devices. Determination of temperature and densities of reactants near the developing features is important, since the structural synthesis is affected by characteristics of the local microenvironment. Consequently, sensors capable of nonintrusive monitoring with high sensitivity and high resolution are essential for real-time atomistic control of reaction kinetics and minimizing trace contamination in plasma processes used to fabricate electronic nanodevices. Such process-monitoring sensors are required to be compact, multiparametric, and immune to the harsh environments of processing plasmas. PPD is intended to satisfy these requirements.

The specific technique used to implement plasma diagnostics with a PPD sensor would be an advanced version of

continuous-wave cavity-ringdown spectroscopy (CW-CRDS) capable of profiling spectral line broadenings in order to derive both Doppler and Stark components. CRDS is based on measurements of the rate of absorption of laser light in an optical resonator. The ultimate sensitivity results from a very long absorption path length within the cavity and immunity to variations in incident laser intensity. The proposed version of this technique would involve the use of multiplexing tunable laser diodes and an actively modulated high-reflectivity optical resonator, thus offering a synergistic combination of simplicity, compactness, high sensitivity, and high resolution.

The multiplexing capabilities of diode lasers could be utilized to make the PPD sensor a single, simple, compact, and inexpensive tool for the acquisition of multiparametric data. A PPD sensor would be capable of continuous measurement of such physical parameters as gas temperature, gas velocity, electron number density, and absolute densities of reacting chemical species. A laser beam can be easily adjusted to analyze the immediate vicinity of the growing nanostructures (or features etched down) in real time. The absorption enhancement in an optical cavity would afford the sensitivity needed for measurement of the temperature and densities of species at concentrations significantly

lower than measurable by other nonintrusive techniques.

It is anticipated that fully developed PPD sensors would enable simultaneous measurement of local temperature and determination of plasma species responsible for the synthesis and functionalization of nanodevices. These sensors would also enable tracking the pathways and origins of damaging contaminants, thereby providing feedback for adjustment of processes to optimize them and reduce contamination. The PPD sensors should also be useful for optimization of conventional microelectronics manufacturing plasma processes.

Going beyond plasma processes for fabrication of electronic devices, PPD sensors could be used for monitoring of atoms, molecules, ions, radicals, clusters, and particles in a variety of other settings, including outer space. Because of their high sensitivity, such sensors could also prove useful for detecting traces of illegal drugs and explosives.

*This work was done by Alexander Bol'shakov while he held a National Research Council associateship award at Ames Research Center.*

*Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-15084-1.*

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## Backed Bending Actuator

Such an actuator could exert a large force at small displacement.

Langley Research Center, Hampton, Virginia

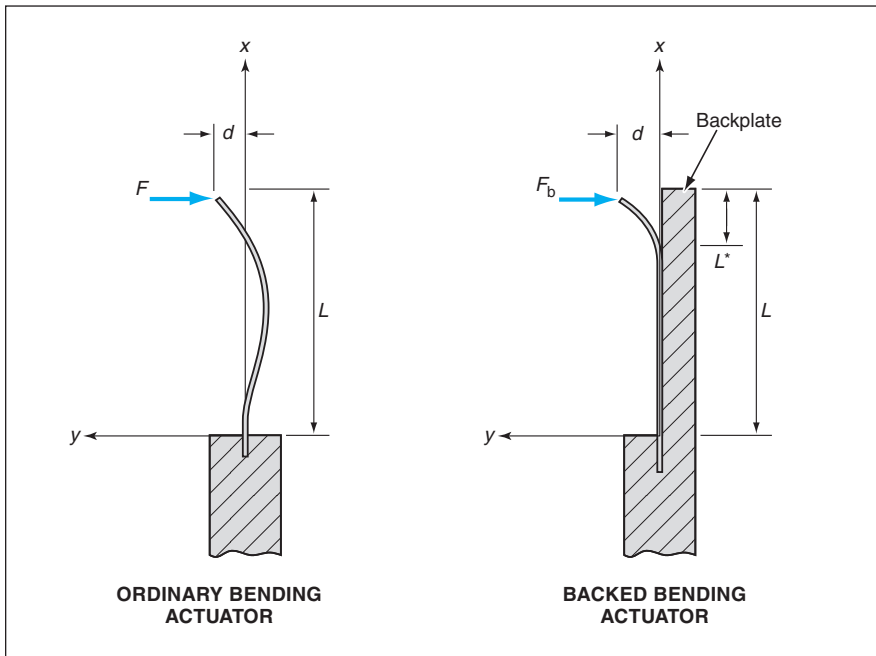
Bending actuators of a proposed type would partly resemble ordinary bending actuators, but would include simple additional components that would render them capable of exerting large forces at small displacements. Like an ordinary bending actuator, an actuator according to the proposal would include a thin rectangular strip that would comprise two bonded layers (possibly made of electroactive polymers with surface electrodes) and would be clamped at one end in the manner of a cantilever beam. Unlike an ordinary bending actuator,

the proposed device would include a rigid flat backplate that would support part of the bending strip against backward displacement; because of this feature, the proposed device is called a backed bending actuator.

When an ordinary bending actuator is inactive, the strip typically lies flat, the tip displacement is zero, and the force exerted by the tip is zero. During activation, the tip exerts a transverse force and undergoes a bending displacement that results from the expansion or contraction of one or more of the bonded lay-

ers. The tip force of an ordinary bending actuator is inversely proportional to its length; hence, a long actuator tends to be weak.

The figure depicts an ordinary bending actuator and the corresponding backed bending actuator. The bending, the tip displacement ( $d$ ), and the tip force ( $F$ ) exerted by the ordinary bending actuator are well approximated by the conventional equations for the loading and deflection of a cantilever beam subject to a bending moment which, in this case, is applied by the differential



A **Backed Bending Actuator** would resemble an ordinary bending actuator except that it would include a backplate that would enable a large displacement together with a large force at small displacements.

expansion or contraction of the bonded layers. The bending, displacement, and tip force of the backed bending actuator are calculated similarly, except that it is necessary to account for the fact that the force  $F_b$  that resists the displacement

of the tip could be sufficient to push part of the strip against the backplate; in such a condition, the cantilever beam would be effectively shortened (length  $L^*$ ) and thereby stiffened and, hence, made capable of exerting a

greater tip force for a given degree of differential expansion or contraction of the bonded layers.

Taking all of these effects into account, the cantilever-beam equations show that  $F_b$  would be approximately inversely proportional to  $d^{1/2}$  for  $d$  less than a calculable amount, denoted the transition displacement ( $d_t$ ). For  $d < d_t$ , part of the strip would be pressed against the backplate. Therefore, the force  $F_b$  would be very large for  $d$  at or near zero and would decrease as  $d$  increases toward  $d_t$ . At  $d > d_t$ , none of the strip would be pressed against the backplate and  $F_b$  would equal the tip force  $F$  of the corresponding ordinary bending actuator. The advantage of the proposal is that a backed bending actuator could be made long to obtain large displacement when it encountered little resistance but it could also exert a large zero-displacement force, so that it could more easily start the movement of a large mass, throw a mechanical switch, or release a stuck mechanism.

*This work was done by Robert C. Costen and Ji Su of Langley Research Center. Further information is contained in a TSP (see page 1) LAR-16441*

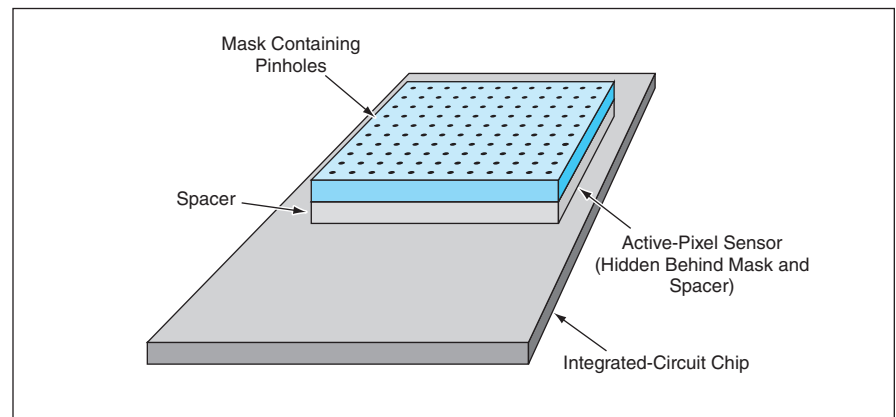
## Compact Optoelectronic Compass

The axis of rotation of the Earth is estimated from the changing direction to the Sun.

NASA's Jet Propulsion Laboratory, Pasadena, California

A compact optoelectronic sensor unit measures the apparent motion of the Sun across the sky. The data acquired by this chip are processed in an external processor to estimate the relative orientation of the axis of rotation of the Earth. Hence, the combination of this chip and the external processor finds the direction of true North relative to the chip: in other words, the combination acts as a solar compass. If the compass is further combined with a clock, then the combination can be used to establish a three-axis inertial coordinate system. If, in addition, an auxiliary sensor measures the local vertical direction, then the resulting system can determine the geographic position.

This chip and the software used in the processor are based mostly on the same design and operation as those of the unit described in "Micro Sun Sensor for Space-



A **Compact Multiple-Pinhole Camera** senses the apparent position of the Sun and its apparent motion across the sky.

craft" (NPO-30867) elsewhere in this issue of *NASA Tech Briefs*. Like the unit described in that article, this unit includes a small multiple-pinhole camera compris-

ing a micromachined mask containing a rectangular array of microscopic pinholes mounted a short distance in front of an image detector of the active-pixel sensor