

This **Atomic Clock** would incorporate a conventional atomic clock and an opto-electronic oscillator in such a manner as to exploit the best features of both.

case, to create two sidebands that differ in frequency by the amount of a hyperfine transition in the ground state of atoms of an element in vapor form in a cell. The combination of these sidebands produces a transparency in the population of a higher electronic level that can be reached from either of the two ground-state hyperfine levels by absorption of a photon. The beam is transmitted through the vapor to a photodetector. The components of light scattered or transmitted by the atoms in the two hy-

perfine levels mix in the photodetector and thereby give rise to a signal at the hyperfine-transition frequency.

The proposed atomic clock would include an OEO and a rubidium- or cesium-vapor cell operating in the CPT/Raman regime (see figure). In the OEO portion of this atomic clock, as in a typical prior OEO, a laser beam would pass through an electro-optical modulator, the modulated beam would be fed into a fiber-optic delay line, and the delayed beam would be fed to a photode-

tor. The electrical output of the photodetector would be detected, amplified, filtered, and fed back to the microwave input port of the modulator.

The laser would be chosen to have the same wavelength as that of the pertinent ground-state/higher-state transition of the atoms in the vapor. The modulator/filter combination would be designed to operate at the microwave frequency of the hyperfine transition. Part of the laser beam would be tapped from the fiber-optic loop of the OEO and introduced into the vapor cell. After passing through the cell, this portion of the beam would be detected differentially with a tapped portion of the fiber-optically-delayed beam. The electrical output of the photodetector would be amplified and filtered in a loop that would control a DC bias applied to the modulator. In this manner, the long-term stability and accuracy of the atomic transition would be transferred to the OEO.

This work was done by Lute Maleki and Nan Yu 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:

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Refer to NPO-30557, volume and number of this NASA Tech Briefs issue, and the page number.

Microfocus/Polycapillary-Optic Crystallographic X-Ray System

This system generates an intense, nearly collimated beam suitable for crystallography.

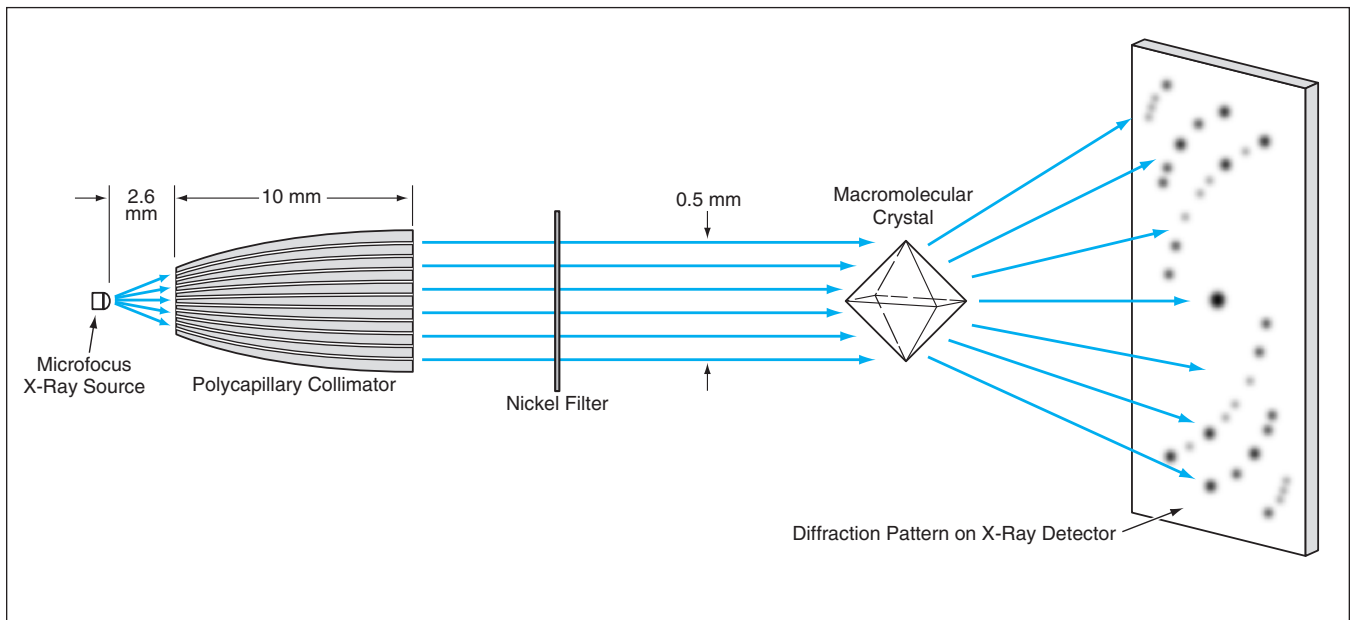
Marshall Space Flight Center, Alabama

A system that generates an intense, nearly collimated, nearly monochromatic, small-diameter x-ray beam has been developed for use in macromolecular crystallography. A conventional x-ray system for macromolecular crystallography includes a rotating-anode x-ray source, which is massive (≥ 500 kg), large (approximately 2 by 2 by 1 m), and power-hungry (between 2 and 18 kW). In contrast, the present system generates a beam of the required brightness from a microfocus source, which is small and

light enough to be mounted on a laboratory bench, and operates at a power level of only tens of watts.

The figure schematically depicts the system as configured for observing x-ray diffraction from a macromolecular crystal. In addition to the microfocus x-ray source, the system includes a polycapillary optic — a monolithic block (typically a bundle of fused glass tubes) that contains thousands of straight or gently curved capillary channels, along which x-rays propagate with multiple reflec-

tions. This particular polycapillary optic is configured to act as a collimator; the x-ray beam that emerges from its output face consists of quasi-parallel subbeams with a small angular divergence and a diameter comparable to the size of a crystal to be studied. The gap between the microfocus x-ray source and the input face of the polycapillary optic is chosen consistently with the focal length of the polycapillary optic and the need to maximize the solid angle subtended by the optic in order to maxi-



This **Microfocus-Source/Polycapillary-Collimator X-Ray System** generates an x-ray flux greater than that of a larger and more power-hungry rotating-anode x-ray system.

mize the collimated x-ray flux. The spectrum from the source contains a significant component of Cu $K\alpha$ (photon energy is 8.08 keV) radiation. The beam is monochromatized (for Cu $K\alpha$) by a nickel filter 10 μm thick.

In a test, this system was operated at a power of 40 W (current of 897 μA at an accelerating potential of 45 kV), with an anode x-ray spot size of $41 \pm 2 \mu\text{m}$. Also tested, in order to provide a standard for comparison, was a commercial rotating-

anode x-ray crystallographic system with a pyrolytic graphite monochromator and a 250- μm pinhole collimator, operating at a power of 3.15 kW (current of 70 mA at an accelerating potential of 45 kV). The flux of collimated Cu $K\alpha$ radiation in this system was found to be approximately 16 times that in the rotating-anode system. Data on x-ray diffraction from crystals of tetragonal form of lysozyme (protein) in this system were found to be of high quality and to be re-

ducible by use of standard crystallographic software.

This work was done by Marshall Joy of Marshall Space Flight Center, Mikhail Gubarev of the National Research Council, and Ewa Ciszak of Universities Space Research Association.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Jim Dowdy, MSFC Commercialization Assistance Lead, at jim.dowdy@nasa.gov. Refer to MFS-31499.

Depth-Penetrating Luminescence Thermography of Thermal-Barrier Coatings

Temperatures at depths can be measured by luminescence decay of suitable thermographic phosphors.

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A thermographic method has been developed for measuring temperatures at predetermined depths within dielectric material layers — especially thermal-barrier coatings. This method will help satisfy a need for noncontact measurement of through-the-thickness temperature gradients for evaluating the effectiveness of thermal-barrier coatings designed to prevent overheating of turbine blades, combustor liners, and other engine parts.

Heretofore, thermography has been limited to measurement of surface and near-surface temperatures. In the thermographic method that is the immediate

predecessor of the present method, a thermographic phosphor is applied to the outer surface of a thermal barrier coating, luminescence in the phosphor is excited by illuminating the phosphor at a suitable wavelength, and either the time dependence of the intensity of luminescence or the intensities of luminescence spectral lines is measured. Then an emissivity-independent surface-temperature value is computed by use of either the known temperature dependence of the luminescence decay time or the known temperature dependence of ratios between intensities of selected luminescence spectral lines. Until

now, depth-penetrating measurements have not been possible because light of the wavelengths needed to excite phosphors could not penetrate thermal-barrier coating materials to useful depths.

In the present method as in the method described above, one exploits the temperature dependence of luminescence decay time. In this case, the phosphor is incorporated into the thermal-barrier coat at the depth at which temperature is to be measured. To be suitable for use in this method, a phosphor must (1) exhibit a temperature dependence of luminescence decay time in the desired range, (2) be thermochemi-