Manufacturing

Aligning Arrays of Lenses and Single-Mode Optical Fibers

A procedure for precise alignment involves the use of an interferometer and positioning stages.

NASA's Jet Propulsion Laboratory, Pasadena, California

A procedure now under development is intended to enable the precise alignment of sheet arrays of microscopic lenses with the end faces of a coherent bundle of as many as 1,000 single-mode optical fibers packed closely in a regular array (see Figure 1). In the original application that prompted this development, the precise assembly of lenses and optical fibers serves as a single-mode spatial filter for a visible-light nulling interferometer. The precision of alignment must be sufficient to limit any remaining wavefront error to a root-mean-square value of less than 1/10 of a wavelength of light. This wavefront-error limit translates to requirements to (1) ensure uniformity of both the lens and fiber arrays, (2) ensure that the lateral distance from the central axis of each lens and the corresponding optical fiber is no more than a fraction of a micron, (3) angularly align the lens-sheet planes and the fiber-bundle end faces to within a few arc seconds, and (4) axially align the lenses and the fiber-bundle end faces to within tens of microns of the focal distance.

Figure 2 depicts the apparatus used in the alignment procedure. The beam of light from a Zygo (or equivalent) interferometer is first compressed by a ratio of 20:1 so that upon its return to the interferometer, the beam will be magnified enough to enable measurement of wavefront quality. The apparatus includes relay lenses that enable imaging of the arrays of microscopic lenses in a charge-coupled-device (CCD) camera that is part of the interferometer. One of the arrays of microscopic lenses is mounted on a 6-axis stage, in proximity to the front face of the bundle of optical fibers. The bundle is mounted on a separate stage. A mirror is attached to the back face of the bundle of optical fibers for retroreflection of light. When a microscopic lens and a fiber are aligned with each other, the affected portion of the light is reflected back by the mirror, recollimated by the microscopic lens, transmitted through the relay lenses and the beam compressor/expander, then split so that half goes to a detector and half to the interferometer. The output of the detector is used as a feedback control signal for the six-axis stage to effect alignment.

The alignment procedure, which is rather complex, can be summarized as follows:

1. In the absence of a sheet array of microscopic lenses, the longitudinal axis

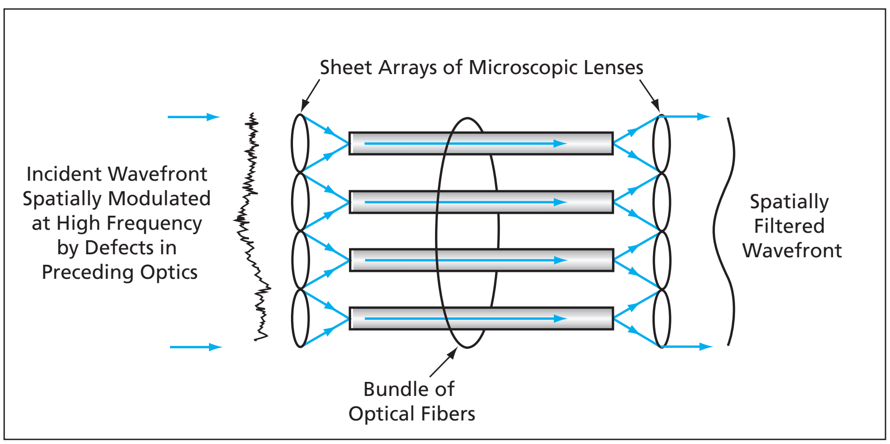

Figure 1. The **Problem Is To Align** two sheet arrays of microscopic lenses with polished end faces of a bundle of optical fibers. The assembly of lenses and fibers is meant to act as a spatial filter.

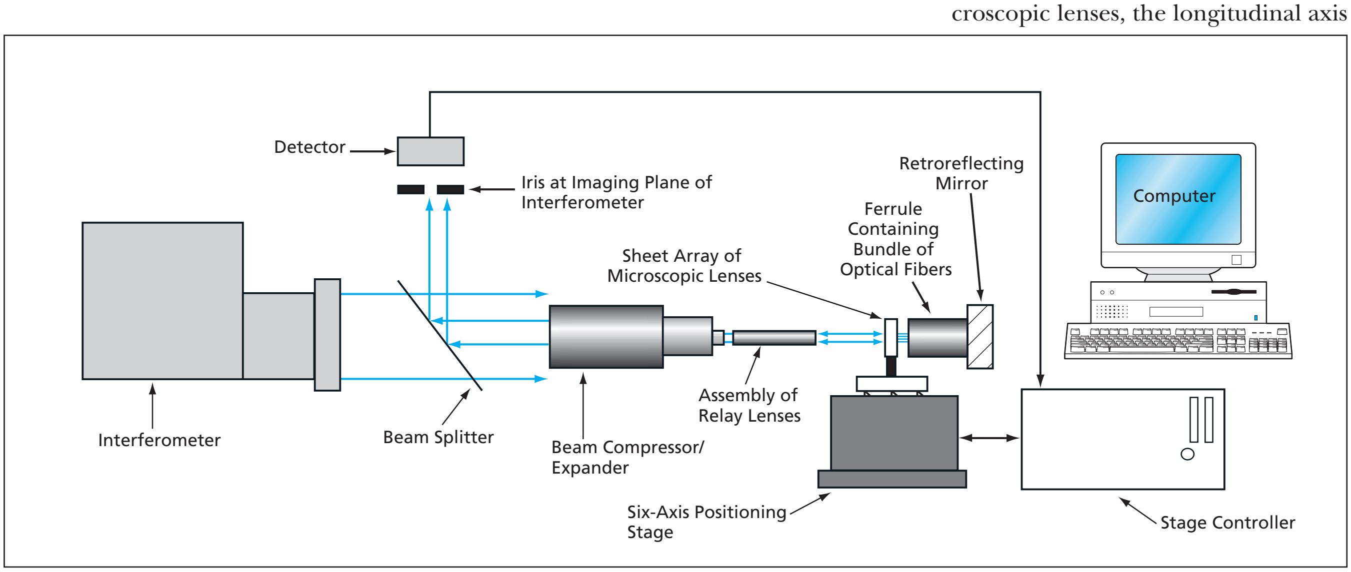

Figure 2. An **Interferometer** is used along with a six-axis positioning stage (and other positioning stages omitted from this view for clarity) to measure and correct the relative position and orientation of the bundle of optical fibers and the sheet array of microscopic lenses.

of the fiber-optic bundle is aligned with the optical axis of the interferometer by use of the reflection from the front face of the bundle.
2. One of the sheet arrays of microscopic lenses is placed in front of the fiber-optic bundle and similarly aligned with the interferometer optical axis by use of the reflection from its front face. As a result, the optical axes of the lens array and the fiber-optic bundle are parallel with each other.
3. The axial position of the lens sheet is adjusted until the interferometric image of light reflected from the front face of the fiber-optic bundle indicates that the lenses are at the proper focal distance.
4. The lateral (relative to the optical axis) position of the lens sheet is adjusted until the interferometric image shows that at least one lens is centered on the end of at least one optical fiber. The lateral coordinates of the six-axis positioner are measured. The lateral position of the lens sheet is further adjusted until another lens/fiber pair is thus centered, and the corresponding coordinates are measured. The two sets of coordinates are used to compute the translation and rotation needed to effect the lateral alignment of the remaining lens/fiber pairs.
5. Guided by the foregoing coordinate measurements, the final adjustments of the lens sheet are made.
6. The lens sheet is bonded to the fiber-optic bundle.
7. The fiber-optic bundle is turned around so that what was previously the back face is now the front face.
8. The retroreflecting mirror is aligned with the optical axis of the interferometer.
9. Steps 1 through 7 are repeated to effect the alignment and bonding of the second lens sheet to what is now the front face of the fiber-optic bundle.

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

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

Refer to NPO-40021, volume and number of this NASA Tech Briefs *issue, and the page number.*

Automatic Control of Arc Process for Making Carbon Nanotubes

Lyndon B. Johnson Space Center, Houston, Texas

An automatic-control system has been devised for a process in which carbon nanotubes are produced in an arc between a catalyst-filled carbon anode and a graphite cathode. The control system includes a motor-driven screw that adjusts the distance between the electrodes. The system also includes a bridge circuit that puts out a voltage proportional to the difference between (1) the actual value of potential drop across the arc and (2) a reference value between 38 and 40 V (corresponding to a current of about 100 A) at which the yield of carbon nanotubes is maximized. Utilizing the fact that the potential drop across the arc increases with the interelectrode gap, the output of the bridge circuit is fed to a motor-control circuit that causes the motor to move the anode toward or away from the cathode if the actual potential drop is more or less, respectively, than the reference potential. Thus, the system regulates the interelectrode gap to maintain the optimum potential drop. The system also includes circuitry that records the potential drop across the arc and the relative position of the anode holder as function of time.

This work was done by Carl D. Scott of **Johnson Space Center**, *Robert B. Pulumbarit of Lockheed Martin, and Joe Victor of Hernandez Engineering. Further information is contained in a TSP (see page 1).*
MSC-23134

Curved-Focal-Plane Arrays Using Deformed-Membrane Photodetectors

It would not be necessary to perform fabrication processing of curved substrates.

NASA's Jet Propulsion Laboratory, Pasadena, California

A versatile and simple approach to the design and fabrication of curved-focal-plane arrays of silicon-based photodetectors is being developed. This approach is an alternative to the one described in "Curved Focal-Plane Arrays Using Back-Illuminated High-Purity Photodetectors" (NPO-30566), *NASA Tech Briefs*, Vol. 27, No. 10 (October 2003), page 10a.

As in the cited prior article, the basic idea is to improve the performance of an imaging instrument and simplify the optics needed to obtain a given level of performance by making an image sensor (in this case, an array of photodetectors) conform to a curved focal surface, instead of designing the optics to project an image onto a flat focal surface. There is biological precedent for curved-focal-surface designs: retinas — the image sensors in eyes — conform to the naturally curved focal surfaces of eye lenses.

The present approach is applicable to both front-side- and back-side-illuminated, membrane photodetector arrays and is being demonstrated on charge-coupled devices (CCDs). The very-large-