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FIBER OPTICS FOR CONTROLS

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ABSTRACT

The challenge of those involved in control-system hardware development is to accommodate an ever-increasing complexity in aircraft control, while limiting the size and weight of the components and improving system reliability. A technology that displays promise towards this end is the area of fiber optics for controls. The primary advantages of employing optical fibers, passive optical sensors, and optically controlled actuators are weight and volume reduction, immunity from electromagnetic effects, superior bandwidth capabilities, and freedom from short circuits and sparking contacts. Since 1975, NASA Lewis has been performing in-house, contract, and grant research in fiber-optic sensors, high-temperature electro-optic switches, and "fly-by-light" control-system architecture. Passive optical sensor development is an essential yet challenging area of work and has therefore received much attention during this period. A major effort to develop fly-by-light control-system technology, known as the Fiber-Optic Control System Integration (FOCSI) program, was initiated in 1985 as a cooperative effort between NASA and the DOD. Phase I of FOCSI, completed in 1986, was aimed at the design of a fiber-optic integrated propulsion/flight control system. Phase II, yet to be initiated, will provide subcomponent and system development, and a system engine test. In addition to a summary of the benefits of fiber optics, the FOCSI program, sensor advances, and future directions in the NASA Lewis program will be discussed.

FIBER OPTICS FOR CONTROLS

Research in fiber optics for controls is aimed at developing the technology necessary to incorporate a totally fiber-optic integrated propulsion flight system (fly-by-light) into advanced aircraft. The program includes the development and testing of passive optical sensors, electro-optic switches for actuator control, and the design, development, and testing of a fiber-optic control system. An outline of the presentation is included.

FIBER OPTICS FOR CONTROLS

DEVELOP THE TECHNOLOGY NECESSARY TO INCORPORATE A TOTALLY FIBER-OPTIC INTEGRATED PROPULSION/FLIGHT CONTROL SYSTEM INTO ADVANCED AIRCRAFT

- **BENEFITS OF EMPLOYING FIBER OPTICS**
- **FIBER-OPTIC CONTROL SYSTEM INTEGRATION PROGRAM**
- **FIBER-OPTIC SENSORS RESEARCH**
- **SELECTED EXAMPLES OF SENSOR DESIGNS**
- **FUTURE DIRECTIONS IN FIBER OPTICS FOR CONTROLS**

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BENEFITS OF FLY-BY-LIGHT CONTROL SYSTEM

The major benefits of a fly-by-light aircraft control system are outlined. Replacing control-system electrical wiring with optical fibers results in a substantial weight and volume savings. Because optical fibers are dielectric, problems with electromagnetic effects (EME - electromagnetic interference, electromagnetic pulse, and lightning) are eliminated. This, in turn, eliminates the need for shielding and surge-quenching circuits. The high bandwidth capability is advantageous for bus lines and offers the potential for all avionics data to be transmitted over a single line. The use of fiber optics also eliminates the threat of fires due to insulation failures or short circuits, which could cause inadvertent actuation of control hardware.

BENEFITS OF FLY-BY-LIGHT CONTROL SYSTEM

- **WEIGHT AND VOLUME REDUCTION**
- **IMMUNITY FROM ELECTROMAGNETIC EFFECTS**
- **HIGH BANDWIDTH**
- **FREEDOM FROM SHORT CIRCUITS/SPARKING CONTACTS**

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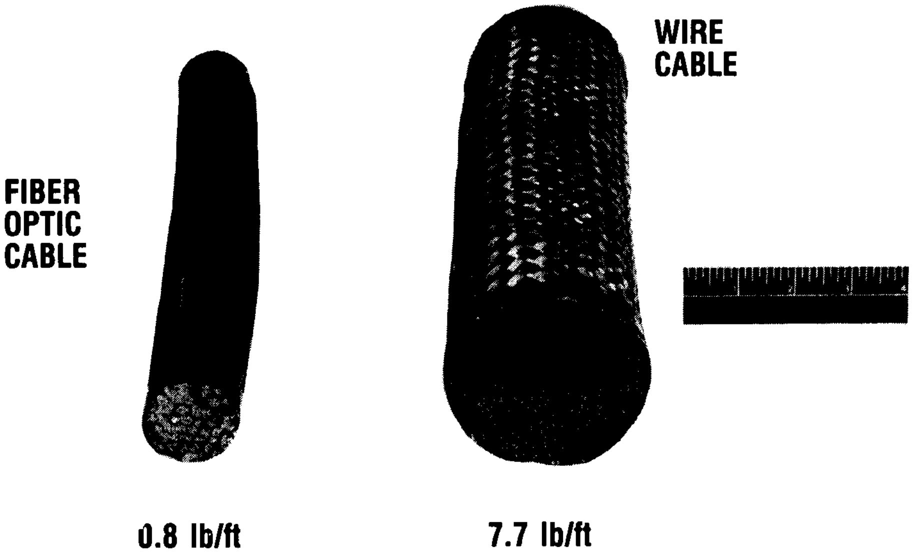
CABLE COMPARISON

A photograph, supplied by UTC/Pratt & Whitney, is presented of a wire cable (right side) which has the same number of sensor/actuator wires as would be employed in a dual, redundant, advanced engine, if all wires were combined into a single cable. The corresponding fiber-optic cable demonstrates an equivalent system employing optical fibers. Note that the volume of the fiber-optic cable is much less, and that the weight/unit length is approximately one-tenth that of the wire cable.

CABLE COMPARISON

ADVANCED GAS TURBINE ENGINE CONTROL SYSTEM WITH 2-D/CD NOZZLE



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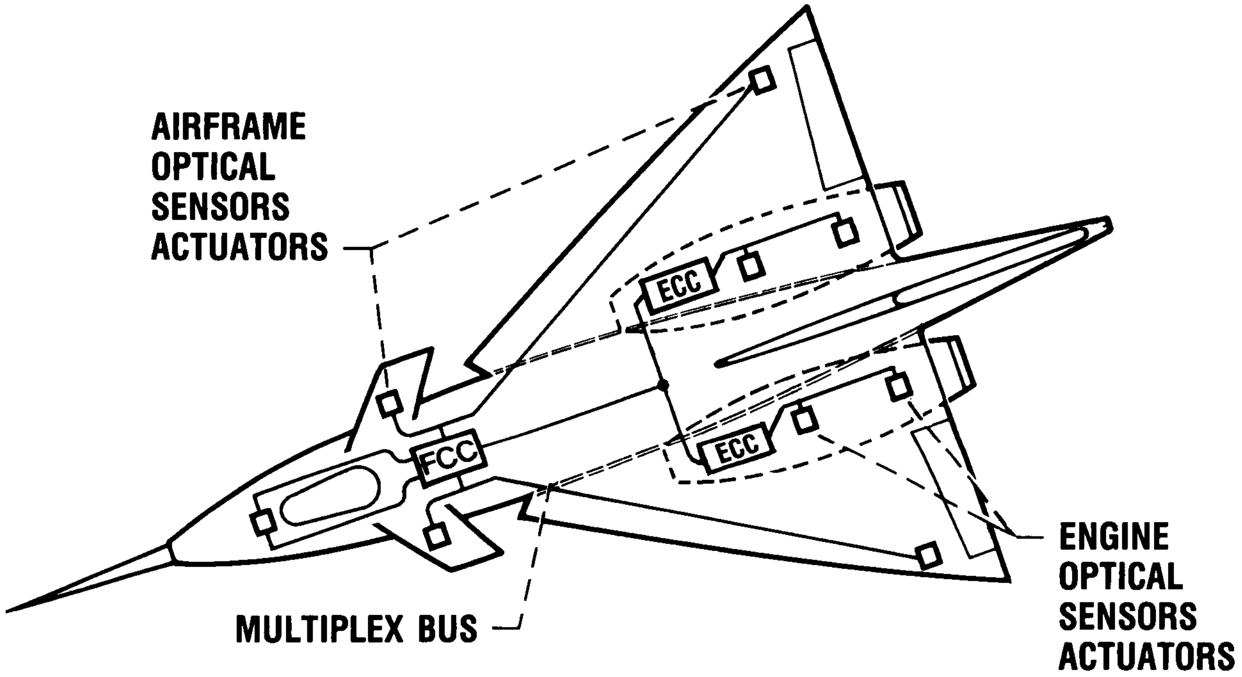
FIBER-OPTIC CONTROL SYSTEM INTEGRATION (AIRCRAFT)

An artist's conception of a fly-by-light aircraft is shown. Sensor/actuator lines and bus lines connecting the engine and flight control computers will employ fiber optics. If, at some point in time, significantly improved reliability and maintainability could be achieved by moving the control off-engine, fiber optics would prove to be of tremendous value in eliminating a huge signal-cable weight penalty.

FIBER-OPTIC CONTROL SYSTEM INTEGRATION (FOCSI)



ECC—ENGINE CONTROL COMPUTER
FCC—FLIGHT CONTROL COMPUTER

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FIBER-OPTIC CONTROL SYSTEM INTEGRATION (OBJECTIVES/SCHEDULE)

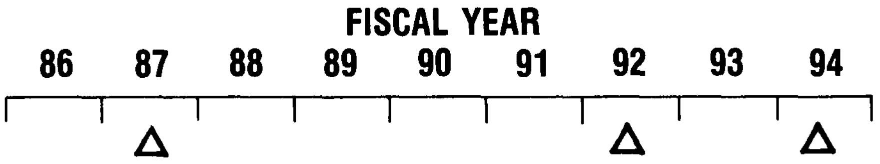
The design, development, and testing of a fiber-optic integrated propulsion/flight control system for an advanced supersonic fighter is the goal of the joint NASA and DOD FOCSI program. Phase I, to assess current technology and to provide system design options, was completed early in FY '87. The Phase II milestones are based on an early FY '89 start date. We feel that continued support for this program is critical to the efficient, timely, and cost-effective development of an integrated fiber-optic control system for aircraft.

FIBER-OPTIC CONTROL SYSTEM INTEGRATION

OBJECTIVE

DEVELOP THE TECHNOLOGY NECESSARY TO INCORPORATE A FIBER-OPTIC INTEGRATED PROPULSION/FLIGHT CONTROL SYSTEM INTO AN ADVANCED SUPERSONIC AIRCRAFT

SCHEDULE



PHASE I: PROPULSION/FLIGHT CONTROL DESIGN

PHASE II: SUBCOMPONENT/SYSTEM DEVELOPMENT
ENGINE TEST

- NASA/DOD COOPERATIVE EFFORT
- RESULTS APPLICABLE TO FUTURE ADVANCED ROTORCRAFT

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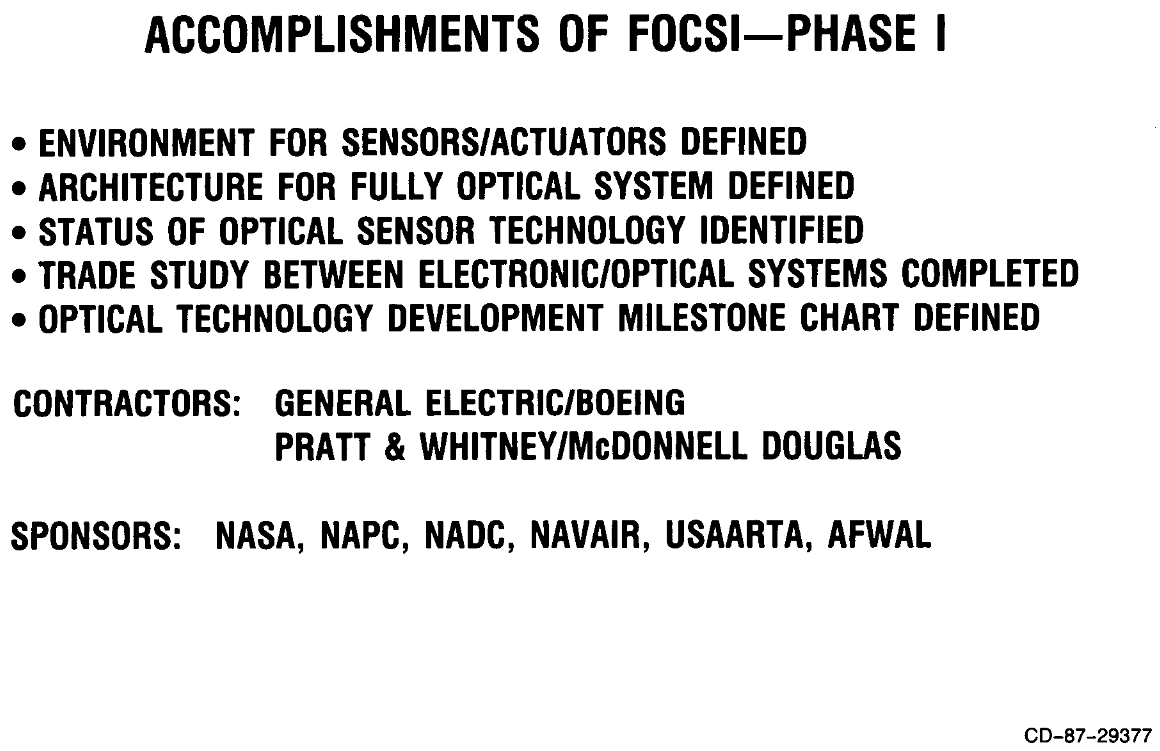
ACCOMPLISHMENTS OF FOCSI - PHASE I

The accomplishments of the FOCSI Phase I effort are summarized. It was determined that there is sufficient advantage in employing a fiber-optic-based control system to warrant continued efforts to develop such a system. It was also determined that it is feasible to build a fiber-optic control system for the development of a data base for this technology, but that further work is necessary in sensors, actuator control, and components to develop an optimum-design, fully fiber-optic integrated control system compatible with advanced aircraft environments.



ACCOMPLISHMENTS OF FOCSI—PHASE I

- **ENVIRONMENT FOR SENSORS/ACTUATORS DEFINED**
- **ARCHITECTURE FOR FULLY OPTICAL SYSTEM DEFINED**
- **STATUS OF OPTICAL SENSOR TECHNOLOGY IDENTIFIED**
- **TRADE STUDY BETWEEN ELECTRONIC/OPTICAL SYSTEMS COMPLETED**
- **OPTICAL TECHNOLOGY DEVELOPMENT MILESTONE CHART DEFINED**

CONTRACTORS: GENERAL ELECTRIC/BOEING
PRATT & WHITNEY/McDONNELL DOUGLAS

SPONSORS: NASA, NAPC, NADC, NAVAIR, USAARTA, AFWAL

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FIBER-OPTIC SENSORS PROGRAM ACCOMPLISHMENTS

To implement a fiber-optic control system requires the development of passive (no electrical connections) optical sensors and optically controlled actuators capable of surviving aircraft environments. NASA Lewis has addressed this critical area of technology since 1975 by developing a wide variety of optical sensors and a high-temperature electro-optic switch through in-house, contract, and grant efforts. Ultimately, the goal is to develop and engine test prototypes of the most promising devices for use in a FOCSI aircraft.

FIBER-OPTIC SENSORS PROGRAM ACCOMPLISHMENTS

• TACHOMETER DEMONSTRATED ON ENGINE	1976
• POSITION ENCODER DEMONSTRATED ON COMPRESSOR GUIDE VANE	1976
• TIP CLEARANCE SENSOR DEMONSTRATED ON COMPRESSOR STAGE	1980
• 800 °C TEMPERATURE SENSOR DEVELOPED (ABSORPTION)	1980
• 1000 °C TEMPERATURE SENSOR DEVELOPED (FABRY-PEROT)	1983
• GALLIUM ARSENIDE PHOTOSWITCH DEVELOPED (260 °C OPERATION)	1985
• HIGH-TEMPERATURE PRESSURE SENSOR DEVELOPED (MICROBEND)	1985
• 1700 °C GAS TEMPERATURE SENSOR DEVELOPED (BLACKBODY)	1986
• PRESSURE SENSOR DEVELOPED (DUAL INTERFEROMETER)	1987

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CURRENT FIBER-OPTIC SENSORS RESEARCH PROGRAM

The wavelength division multiplexed (WDM) position encoder and the SiC etalon are presented in more detail later. Intensity sensor loss compensation schemes refer to methods which provide referencing to reduce or to eliminate problems associated with unwanted changes in intensity which occur outside of the sensor. Two methods have been explored: a fiber-optic loop and a four-fiber approach. The rangefinder employs a variation of the fiber-optic loop method and a novel signal-processing scheme to determine distances. The purpose of the electro-optic architecture (EOA) study is to determine the optimum EOA necessary for servicing remote clusters of sensors and actuators in a fly-by-light aircraft. Research on the final two sensors is currently being initiated.

CURRENT FIBER-OPTIC SENSORS RESEARCH PROGRAM

- **WAVELENGTH DIVISION MULTIPLEXED (WDM) POSITION ENCODER**
- **SILICON CARBIDE ETALON TEMPERATURE SENSOR**
- **INTENSITY SENSOR LOSS COMPENSATION SCHEMES**
- **TIME DIVISION MULTIPLEXED RANGEFINDER**
- **ELECTRO-OPTIC ARCHITECTURE STUDY**
- **IMPROVED 800 °C TEMPERATURE SENSOR (ABSORPTION)**
- **NORMAL SHOCK POSITION SENSOR**

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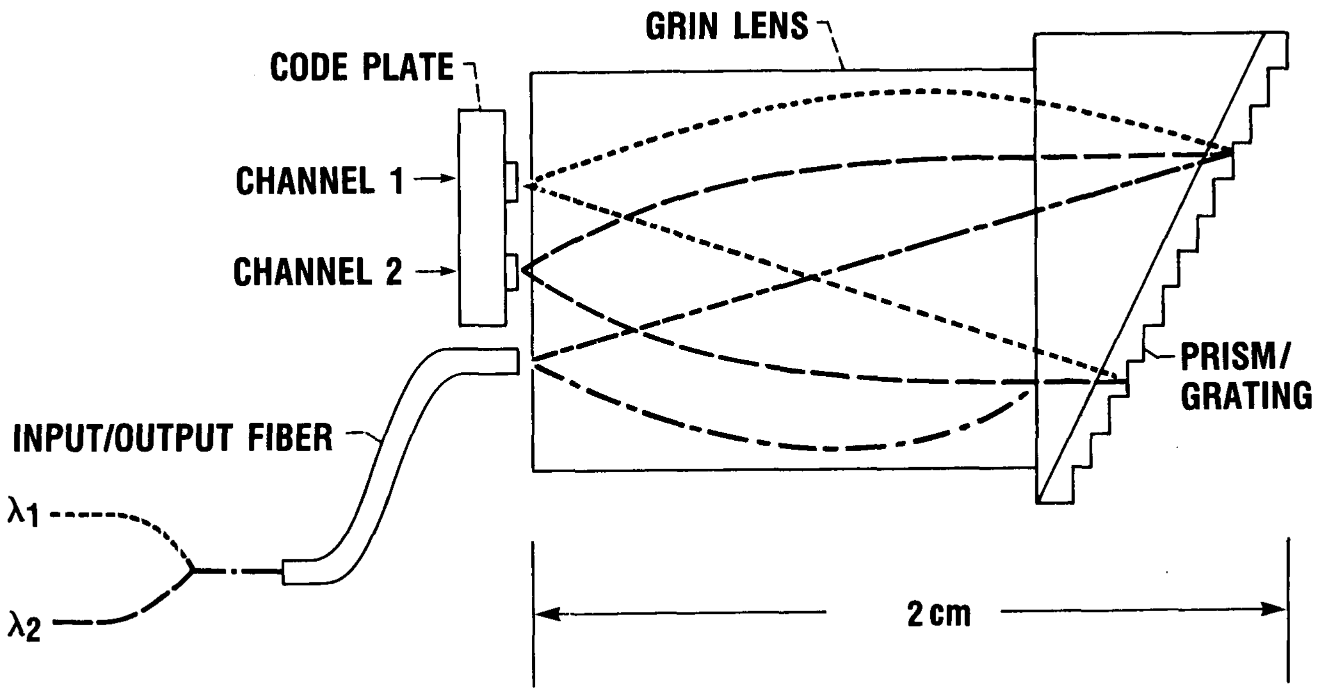
WAVELENGTH DIVISION MULTIPLEXED OPTICAL ENCODER

One sensor being developed is a wavelength division multiplexed (WDM) optical encoder. It uses a micro-optical wavelength multiplexer/demultiplexer in conjunction with a reflective code plate. This approach results in a compact, rugged, and potentially inexpensive device. The multiplexer unit consists of a 5-mm-diameter graded index (GRIN) rod lens epoxied to a prism/grating assembly. Broadband light from LED's enters the transducer by way of the encoder input/output fiber. The multiplexer disperses the broadband spectrum across the channels of the reflective code plate. Those wavelengths directed to a channel in the logic 0 state are absorbed by the code plate. Those wavelengths directed to a channel in the logic 1 state are reflected by the code plate and retransmitted to the input/output fiber.

WAVELENGTH DIVISION MULTIPLEXED OPTICAL ENCODER



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OUTPUT SPECTRUM OF WAVELENGTH DIVISION MULTIPLEXED ENCODER

At the receiver of the WDM optical encoder, demultiplexing is performed by a second grating assembly which disperses the spectrum onto a photodiode array. A typical spectrum is shown. The pattern of "on"-peaks (logic 1) and "off"-valleys (logic 0) defines the position of the actuator to 10-bit resolution. Currently, a prototype encoder is being constructed for future engine and flight tests.

OUTPUT SPECTRUM OF WAVELENGTH DIVISION MULTIPLEXED ENCODER

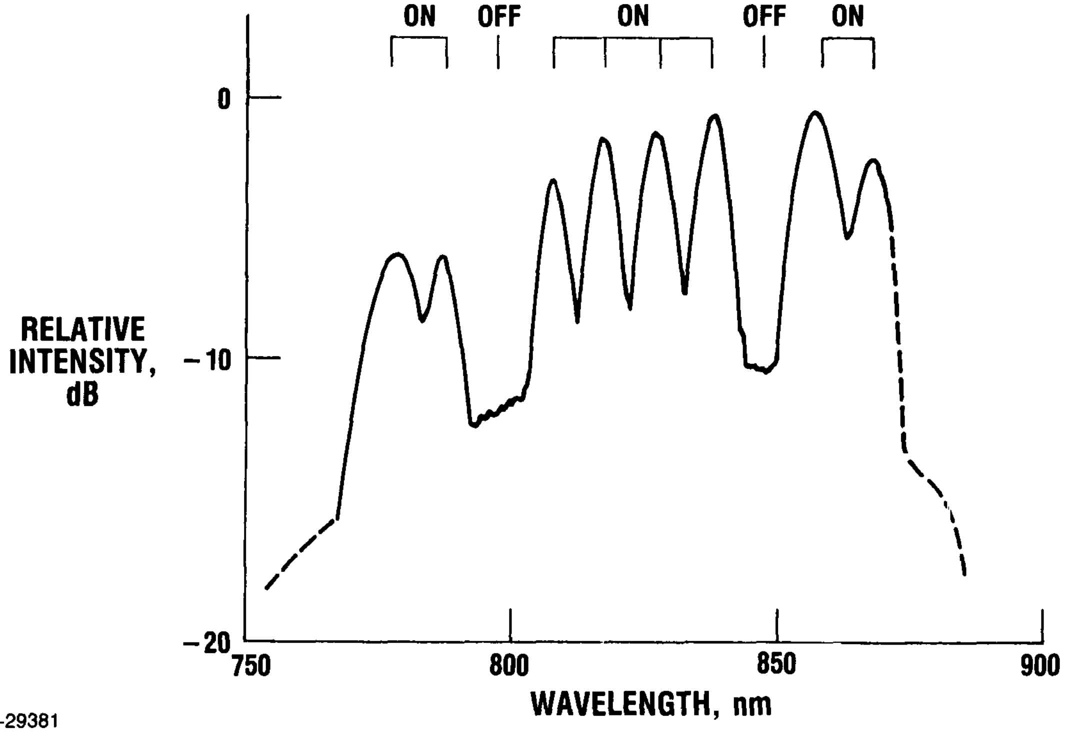

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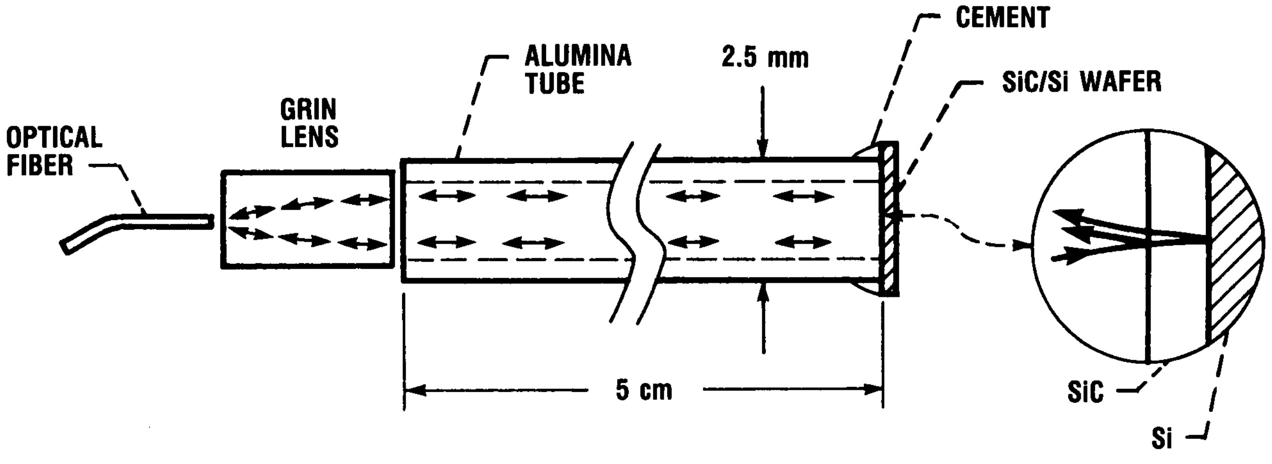
DIAGRAM OF SEMICONDUCTOR-ETALON TEMPERATURE SENSOR

A schematic diagram of a semiconductor etalon temperature sensor is presented. The sensing element is a silicon carbide (SiC) etalon on silicon (Si). Light incident on the etalon is partially reflected from both of its surfaces. Interference patterns from these reflected beams can be related to the optical thickness of the etalon, which, in turn, is a function of the temperature. An optical fiber delivers light to the sensor. A graded index rod (GRIN) microlens collimates this light and directs it towards the sensing etalon. Light reflected by the etalon is recoupled into the fiber by the GRIN lens. A dual interferometer (not shown) system is employed to determine the optical thickness.

SEMICONDUCTOR-ETALON TEMPERATURE SENSOR



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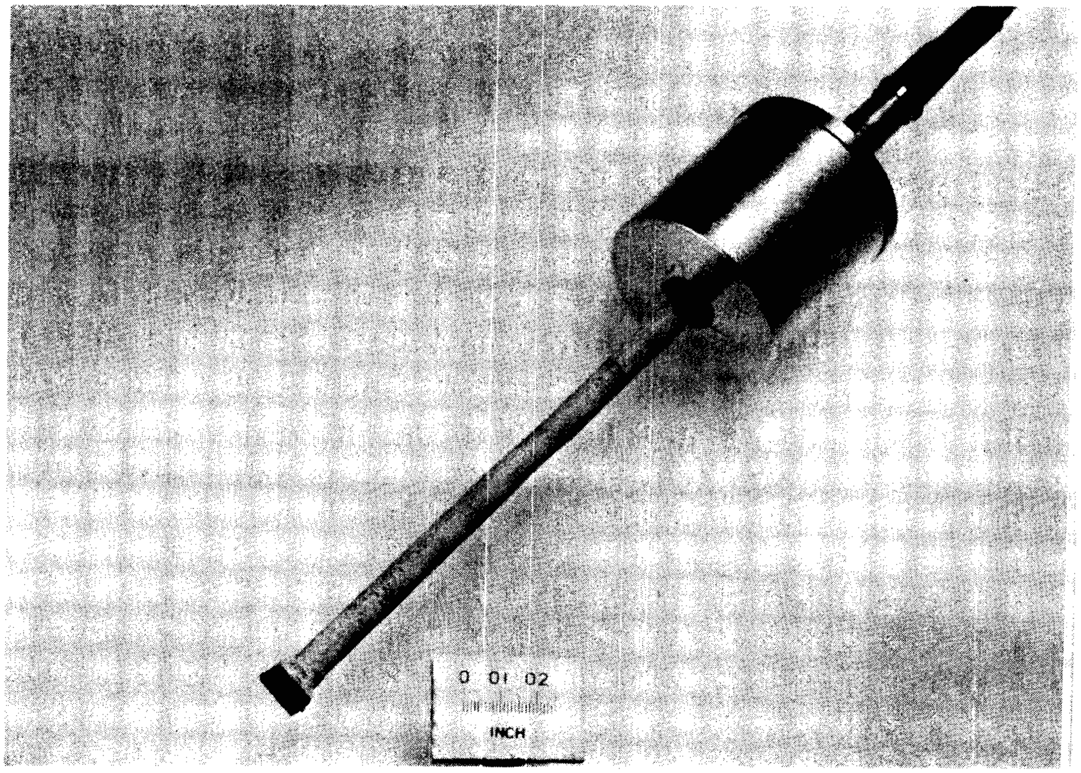
PHOTOGRAPH OF SEMICONDUCTOR-ETALON TEMPERATURE SENSOR

A photograph of the original prototype temperature sensor is presented. To permit the measurement of temperatures significantly higher than can be withstood by the fiber and graded index (GRIN) rod lens, an alumina tube positions the sensing etalon a distance of 5 cm from the GRIN lens. The sensing etalon is a single-crystal film of silicon carbide (SiC) with a thickness of 18 µm. A silicon substrate provides mechanical support to the SiC and serves to protect its surface. A smaller, more advanced version of the sensor is currently being constructed.

SEMICONDUCTOR-ETALON TEMPERATURE SENSOR



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