Microfabricated Optical Compressive Load Sensors

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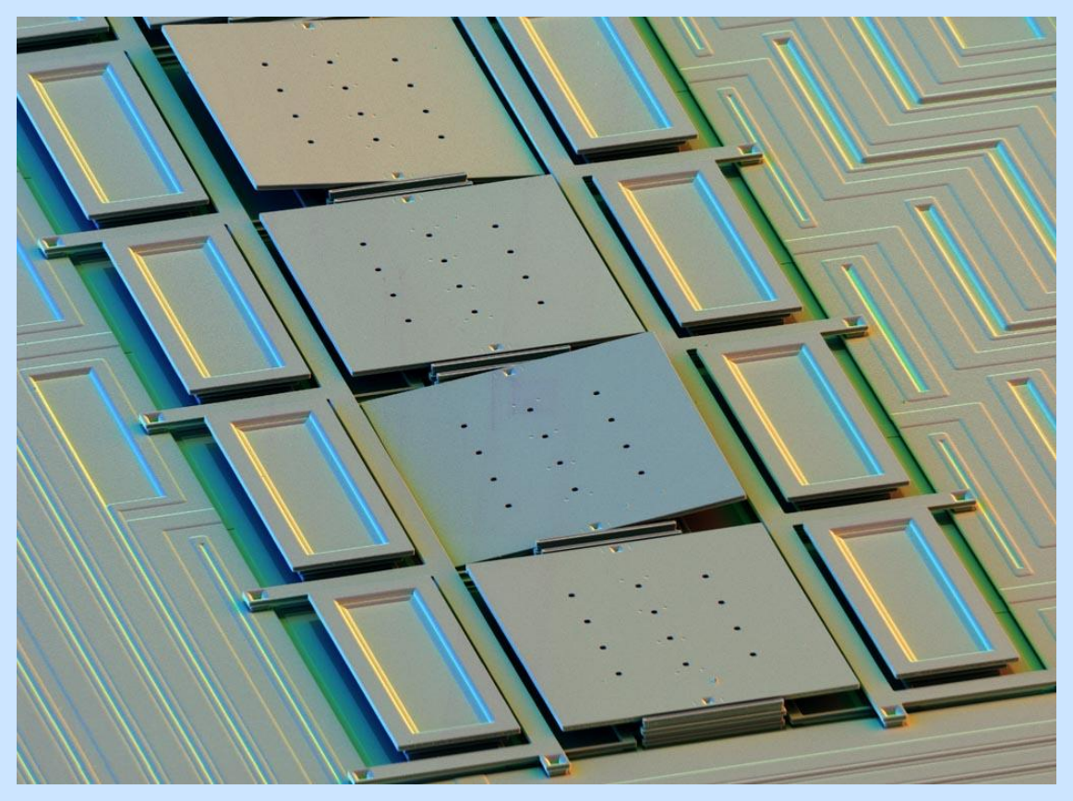
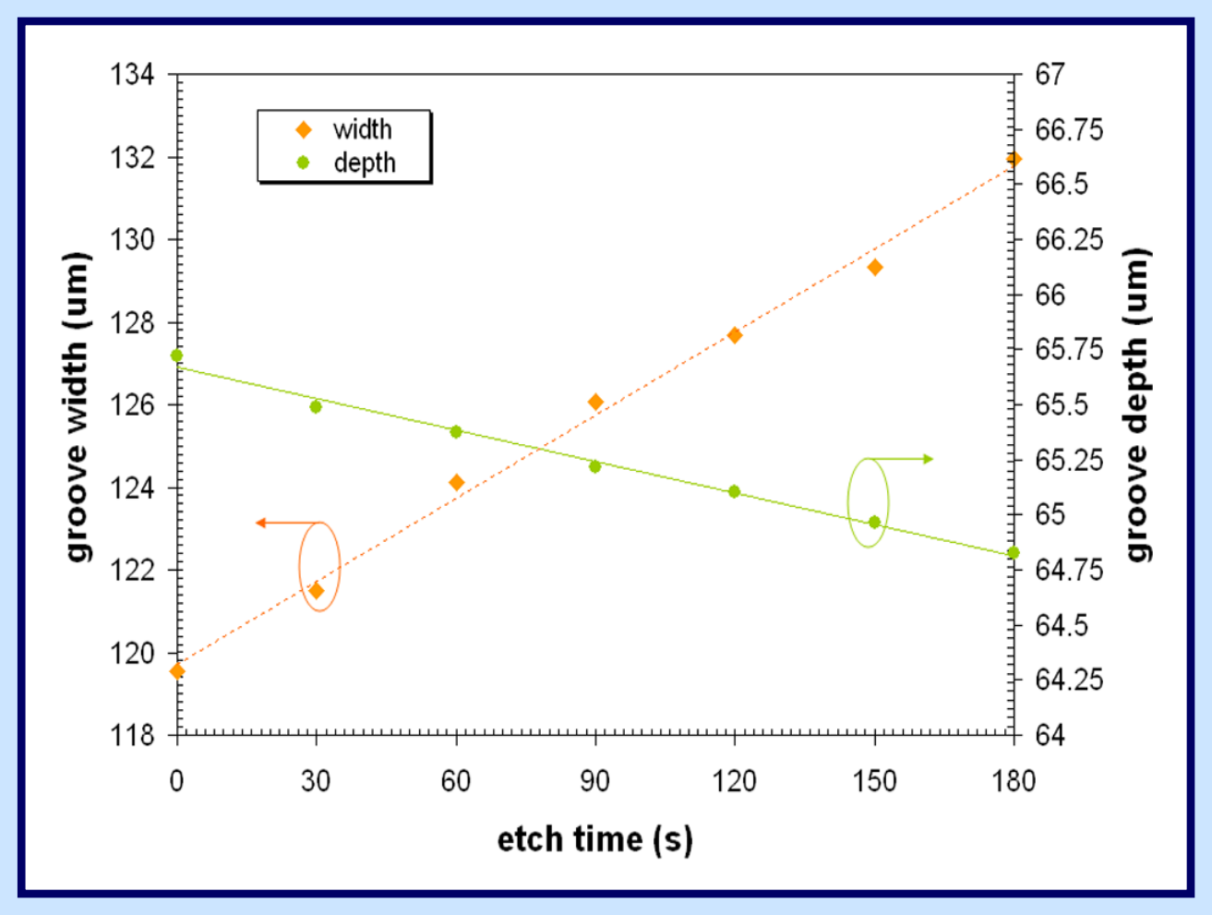
Introduction

We demonstrate novel optically-addressable compressive load sensors consisting of bulk micromachined single-crystal silicon transducers integrated with fiber Bragg grating (FBG) sensing elements. These devices constitute a new class of compact optical sensors realized through the integration of mechanical components constructed via microelectromechanical systems (MEMS) fabrication technologies and strain sensitive elements based on FBGs. In this work we present experimental results for an "optical force probe" capable of sensing compressive loading transverse to the long-axis of the fiber.



Fabrication

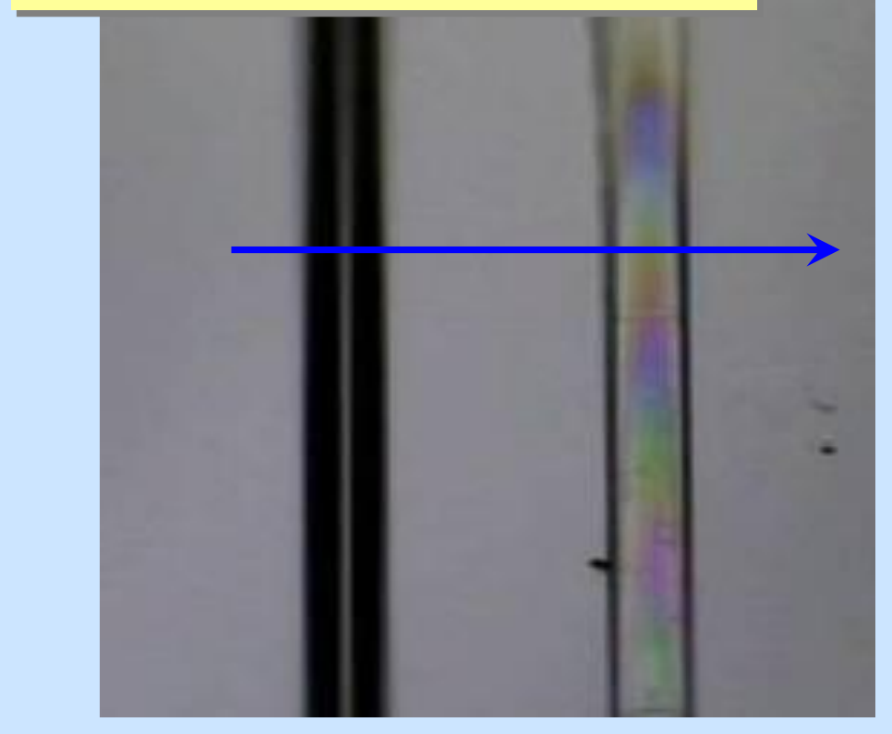
Fiber-Constraint Grooves

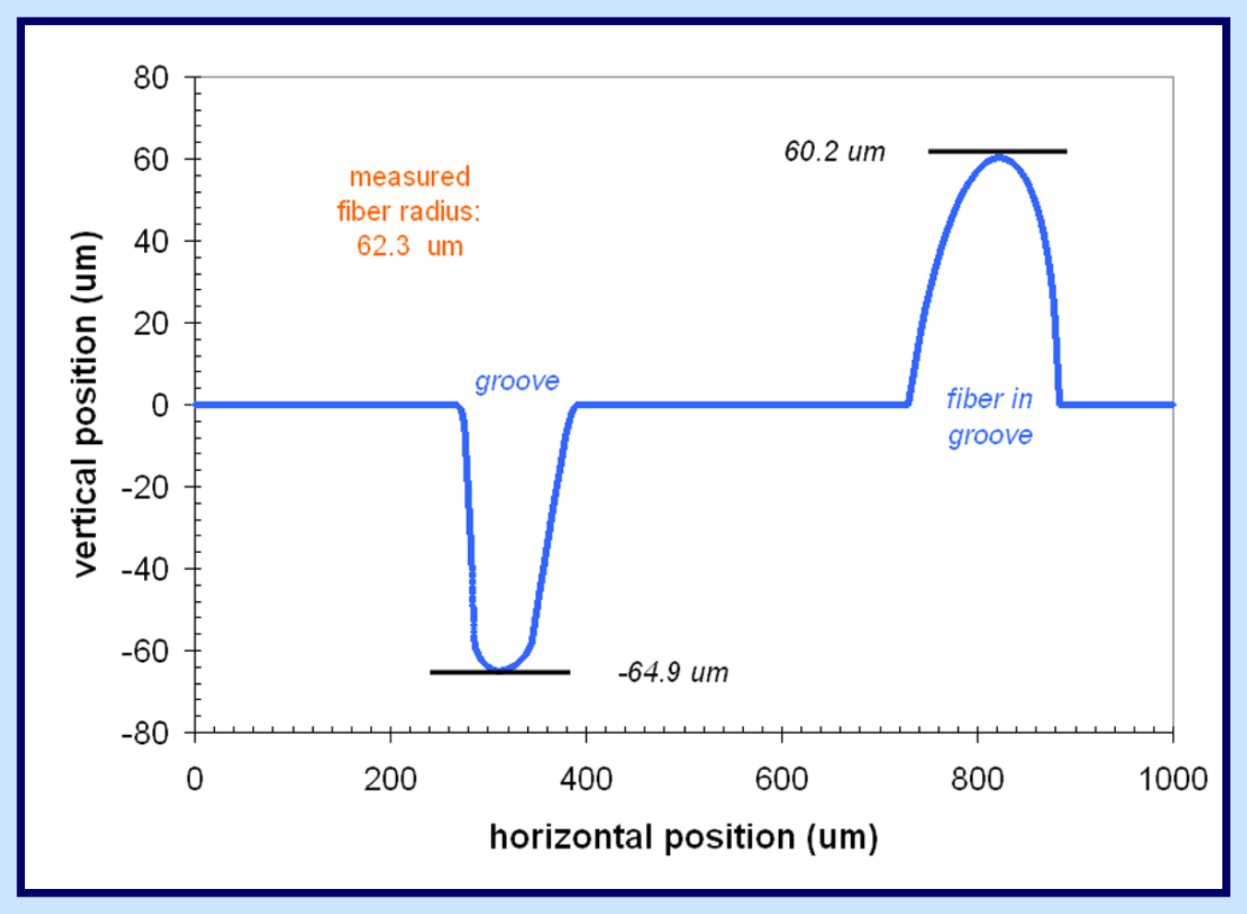


variation in groove depth = -0.31 μm/min

variation in groove width = 4.09 μm/min

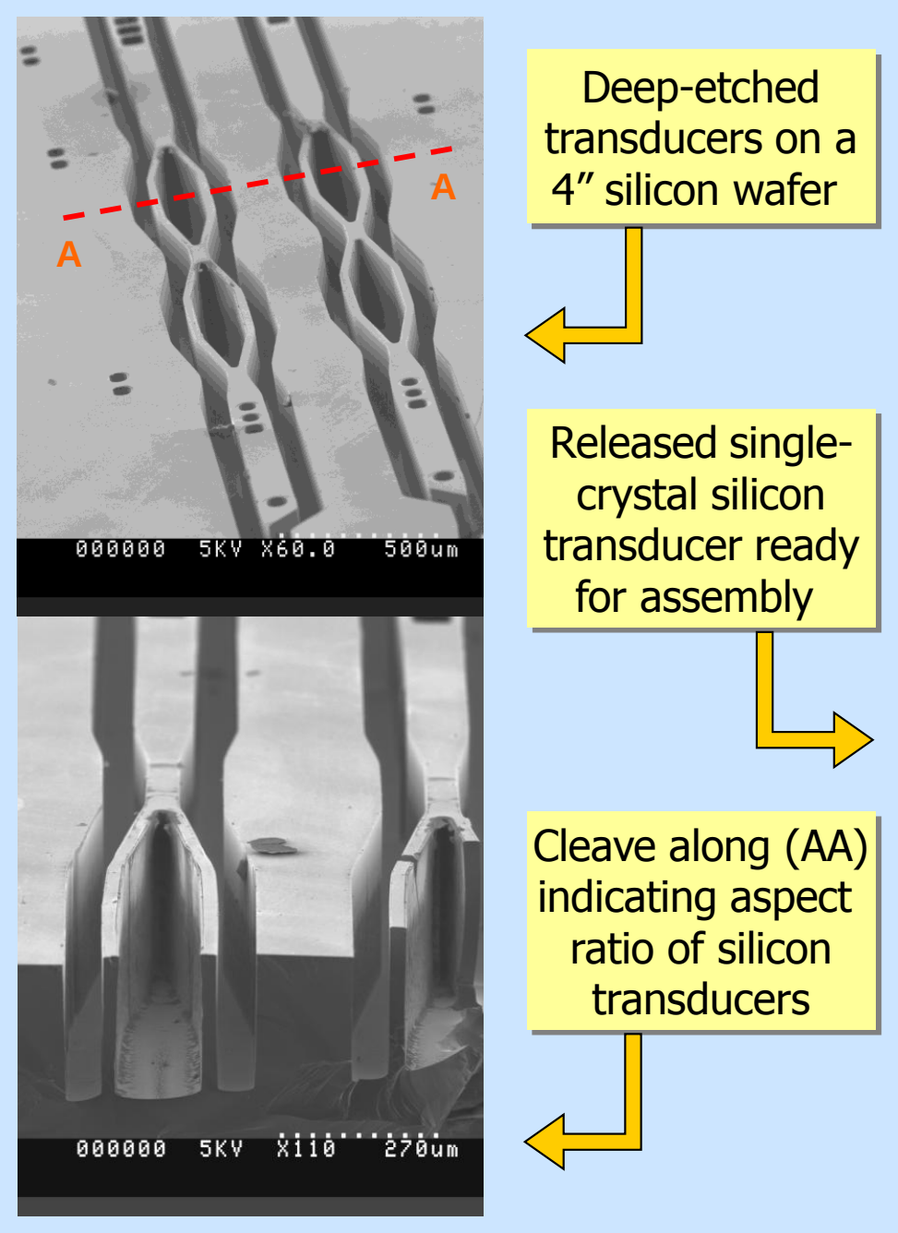
"Newton rings" confirm ideal match to bare silica fiber





For the first step in the fabrication procedure, a groove is defined in the surface of the silicon wafer in order to constrain the location of the optical fiber along the transducer element. We have developed a tuning process to achieve a near ideal semicircular cross-section, allowing for intimate contact with the stripped fiber, as indicated above.

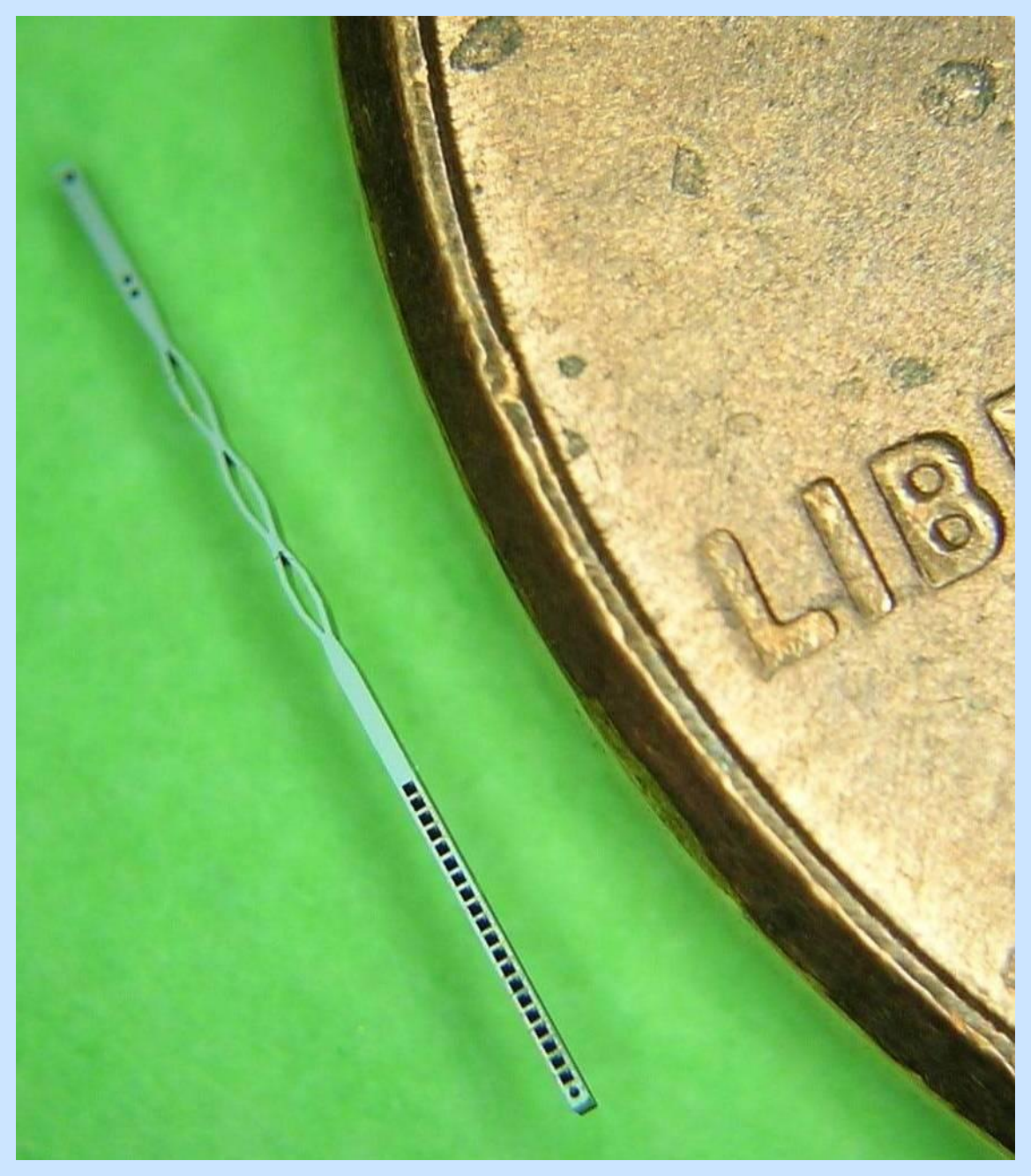
Bulk Micromachined Transducers

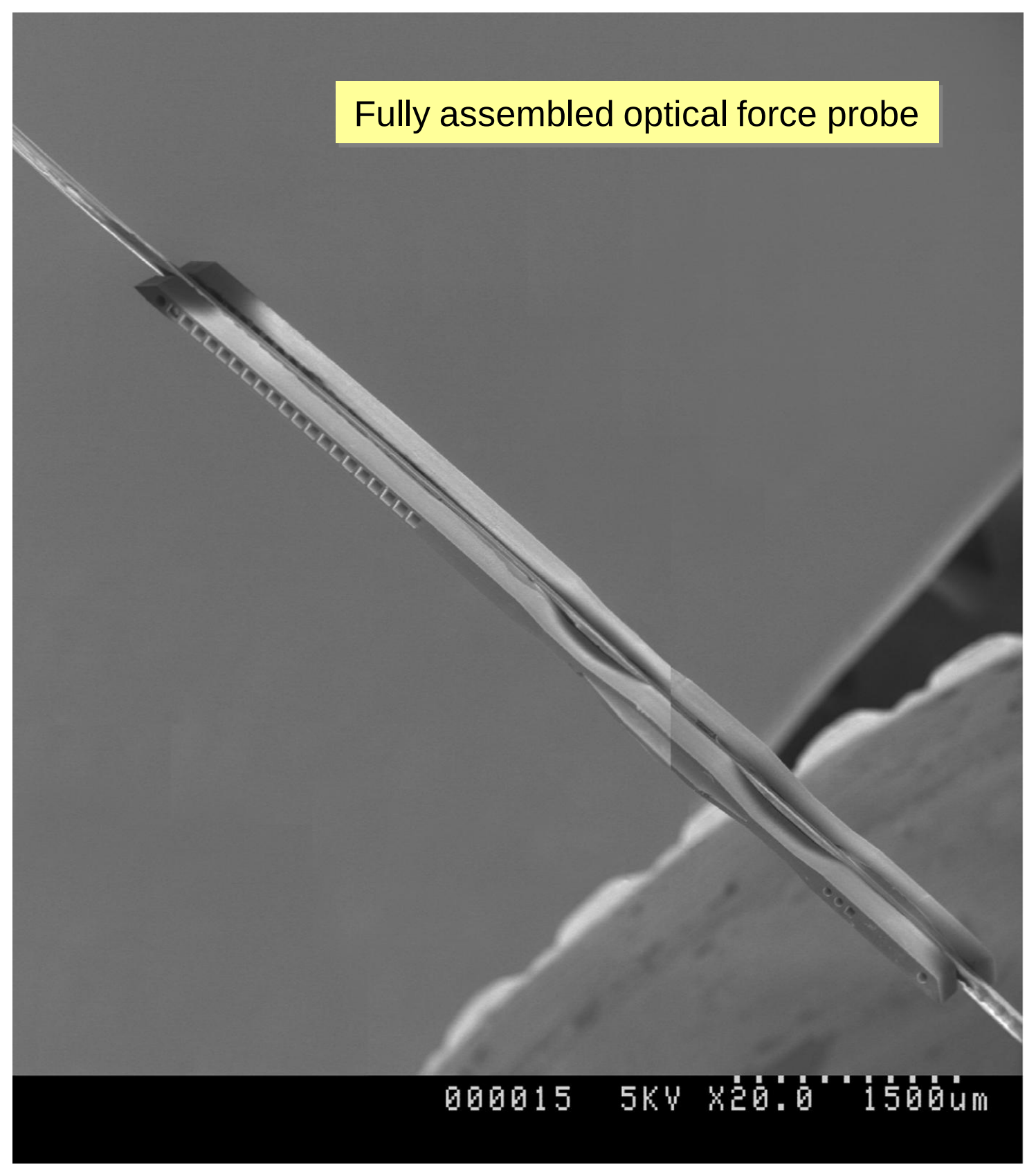


Deep-etched transducers on a 4" silicon wafer

Released single-crystal silicon transducer ready for assembly

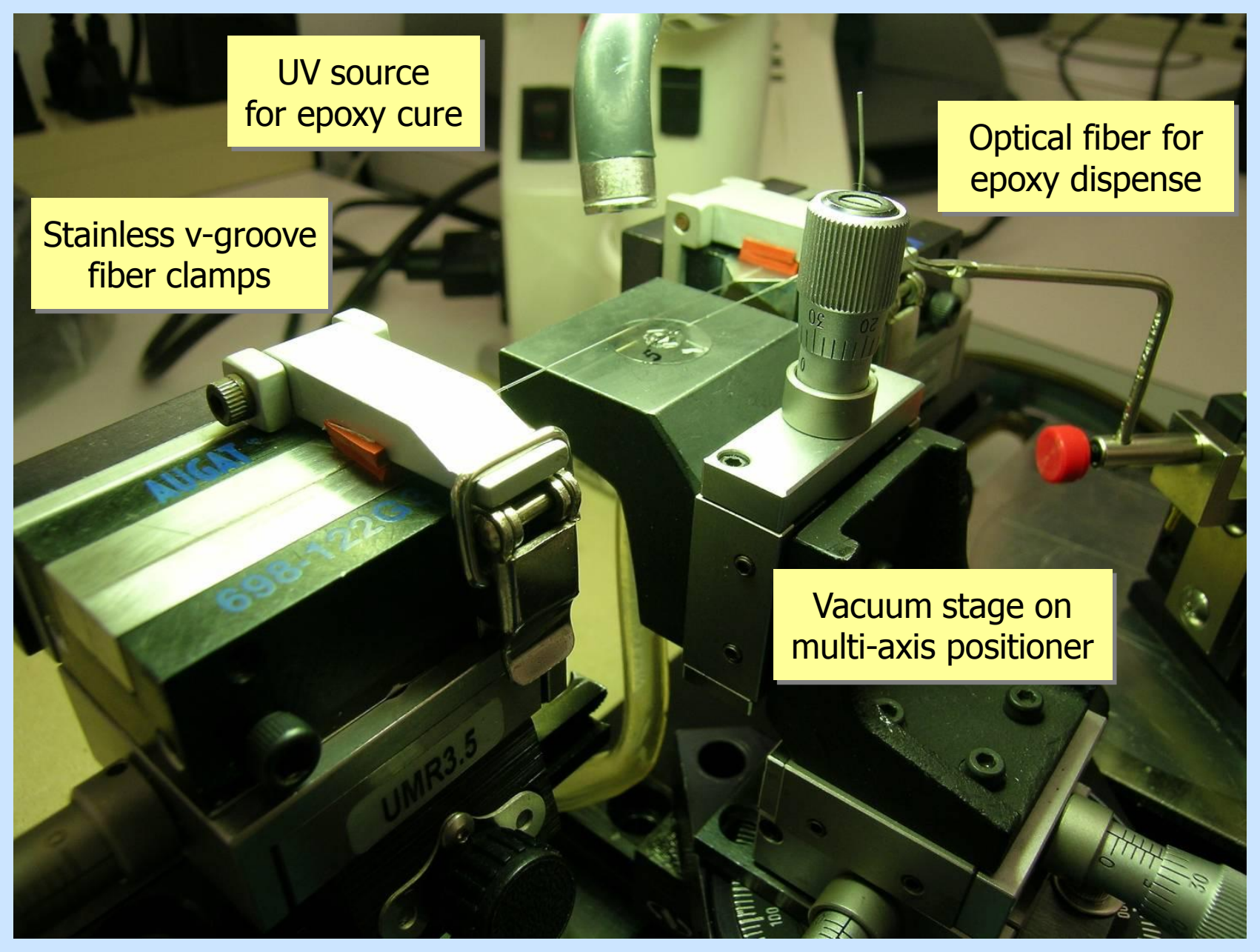
Cleave along (AA) indicating aspect ratio of silicon transducers



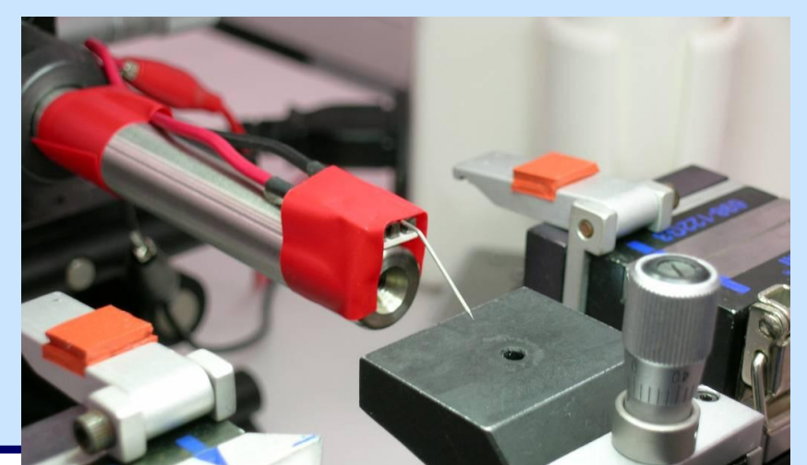


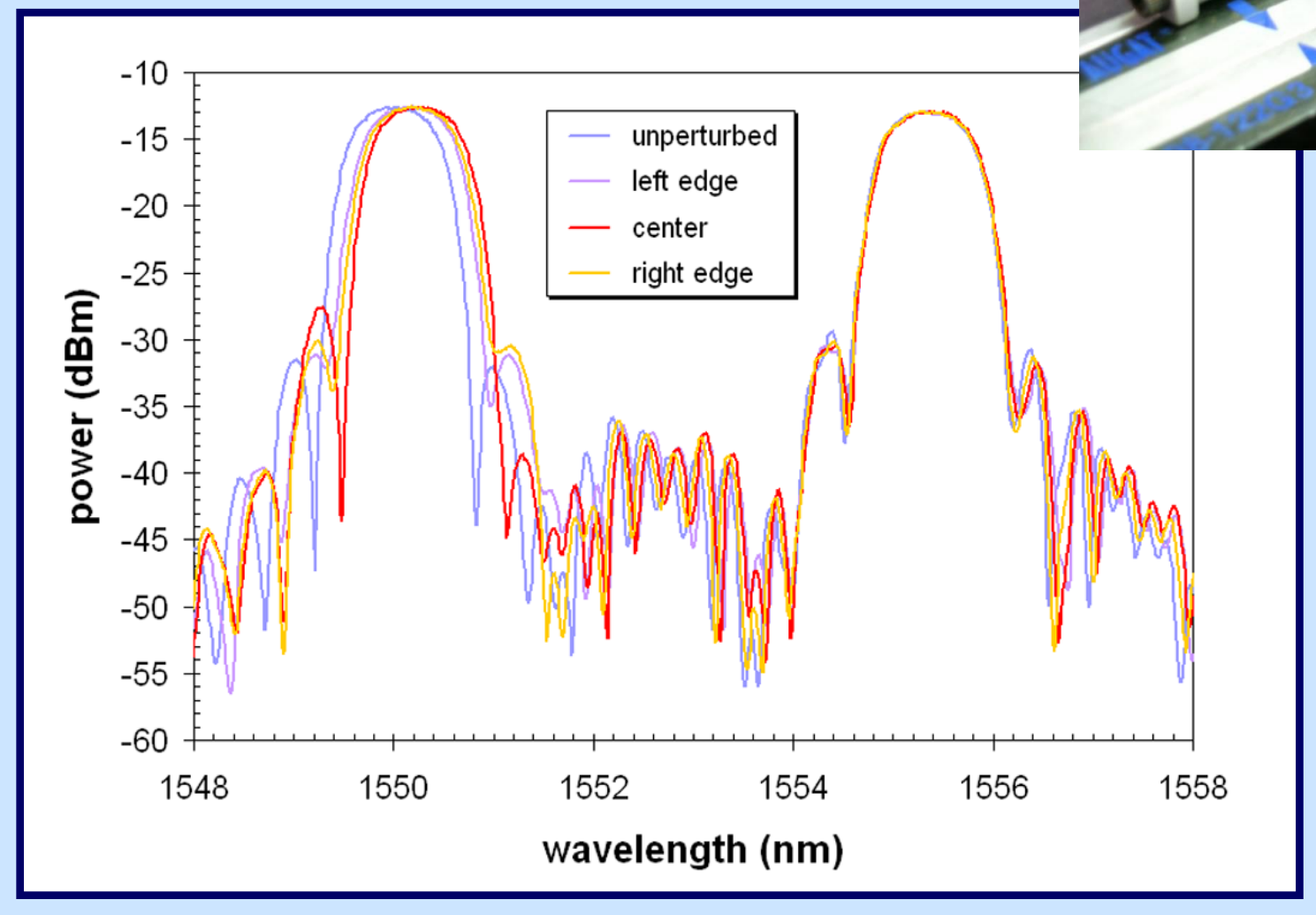
Fully assembled optical force probe

Optical Force Probe Assembly



Joining of the optical fiber sensor and silicon transducers takes place in a custom designed alignment station. Intimate bonding is realized through the use of a dual-cure epoxy.

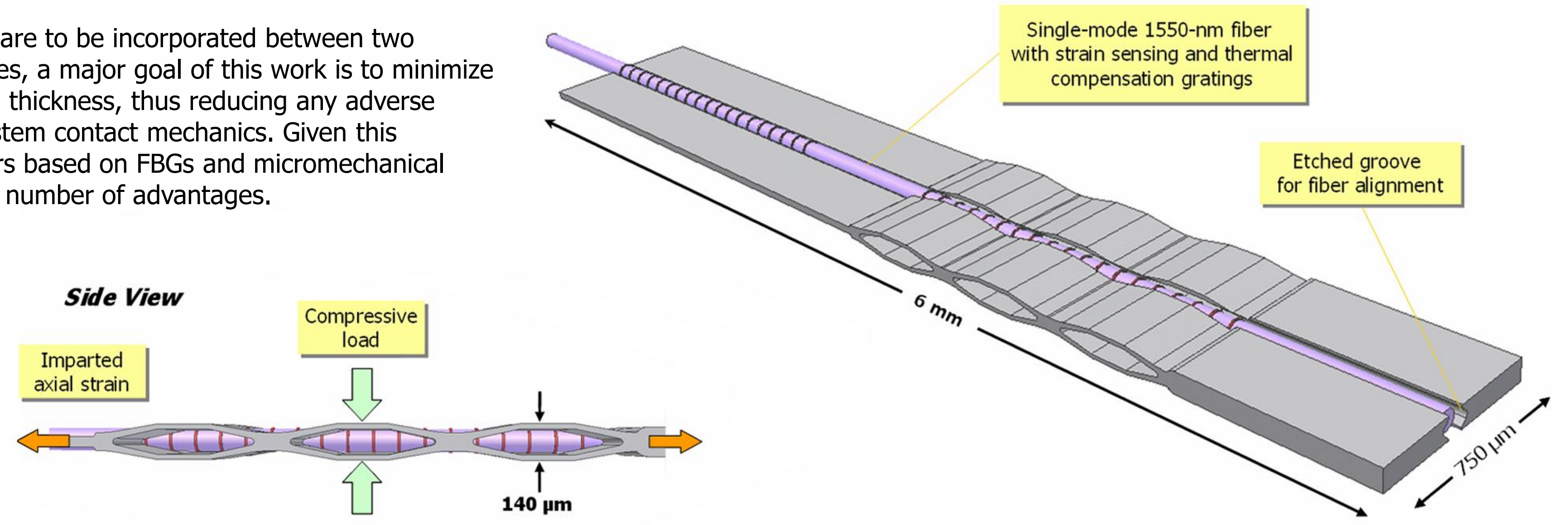




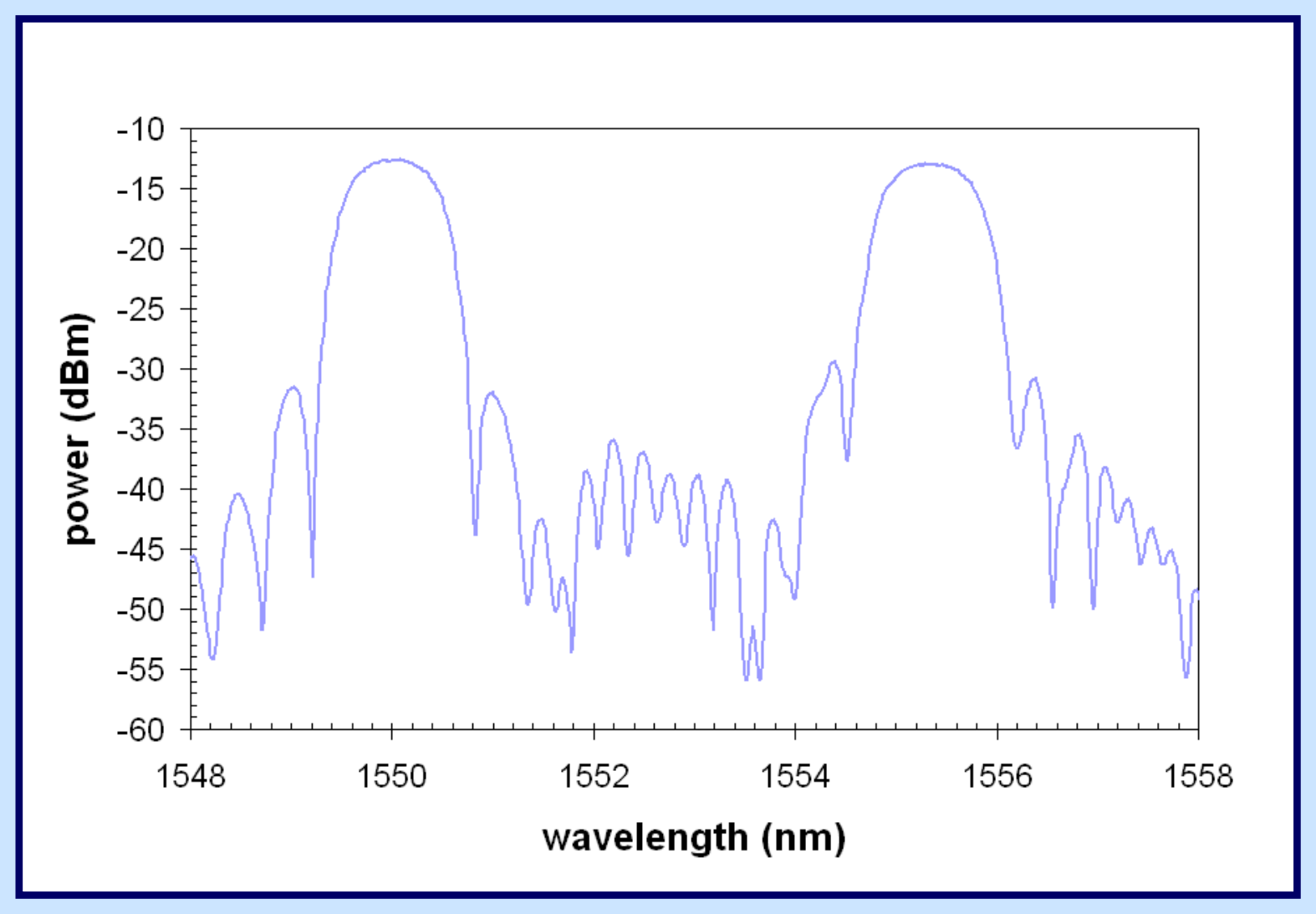
To accurately locate the gratings, we use a localized heating technique. Scanning a heated tungsten probe along the fiber, the center of the grating may be found to an estimated accuracy of ~250 μm.

Device Design

As these sensors are to be incorporated between two contacting surfaces, a major goal of this work is to minimize the overall device thickness, thus reducing any adverse effects on the system contact mechanics. Given this constraint, sensors based on FBGs and micromechanical structures offer a number of advantages.

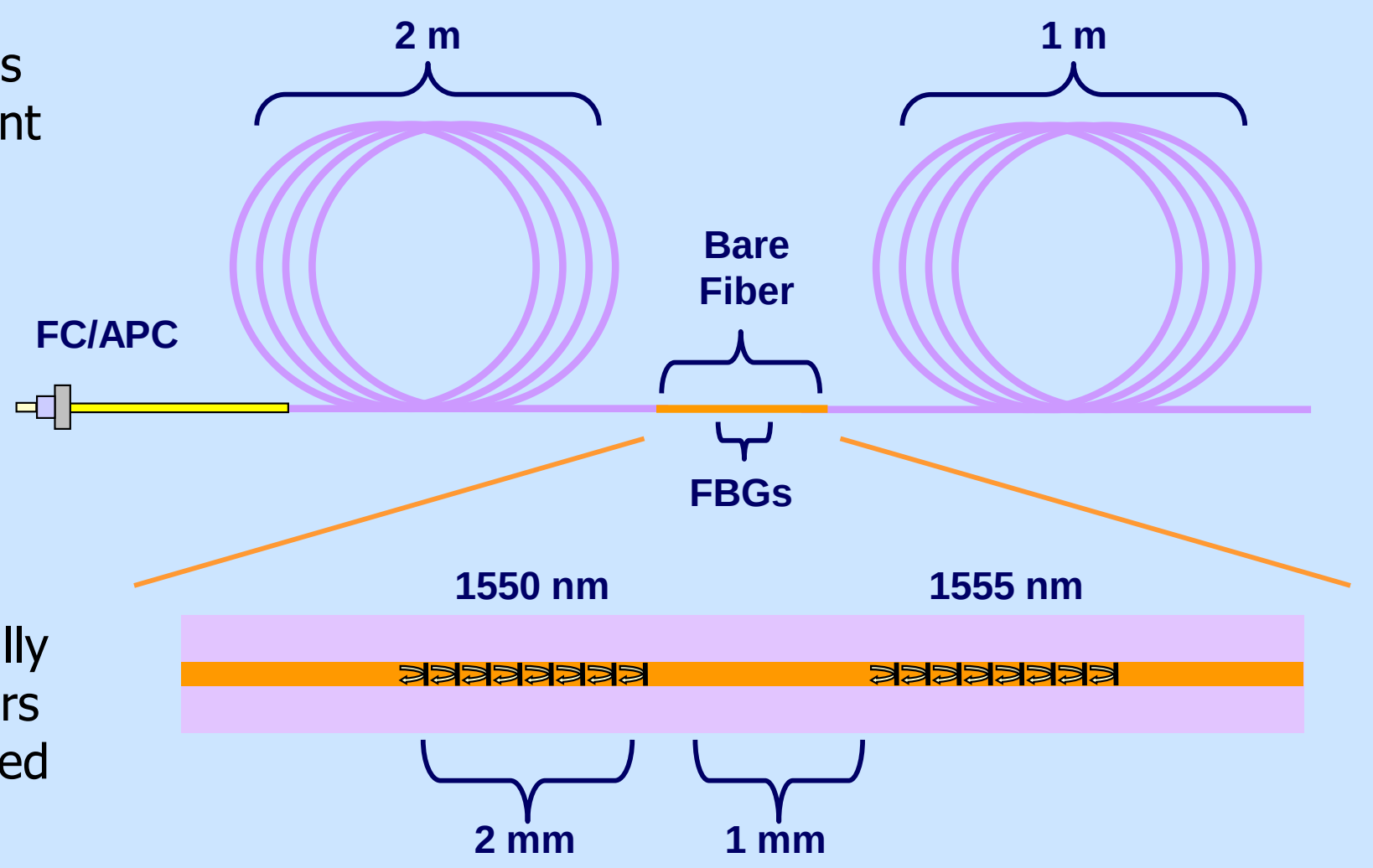


Optical Fiber Sensor



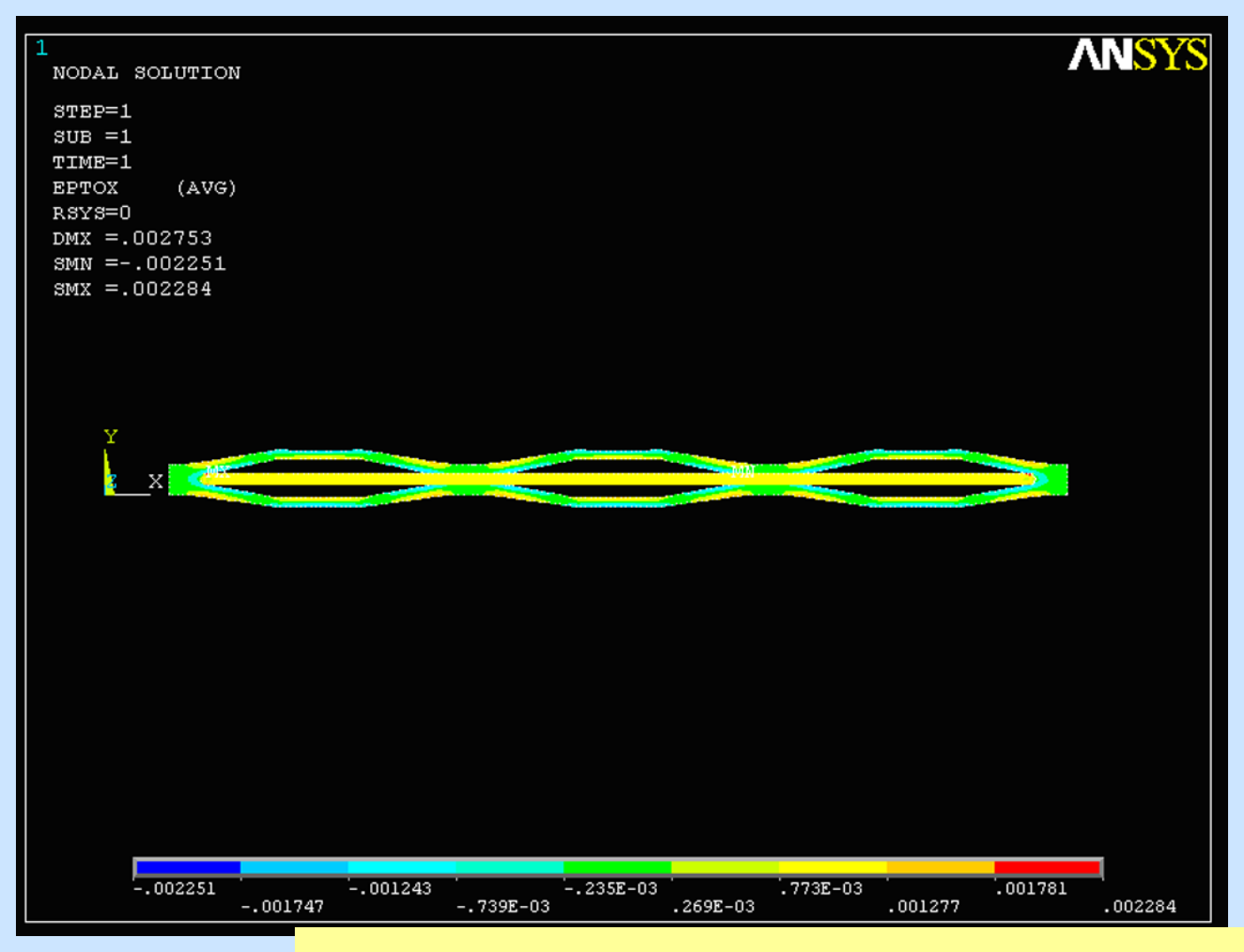
The use of FBGs as the sensing element allows for passive operation with exquisite strain sensitivity.

Utilizing suitable multiplexing techniques, large arrays of individually addressable sensors may be incorporated in a single fiber.

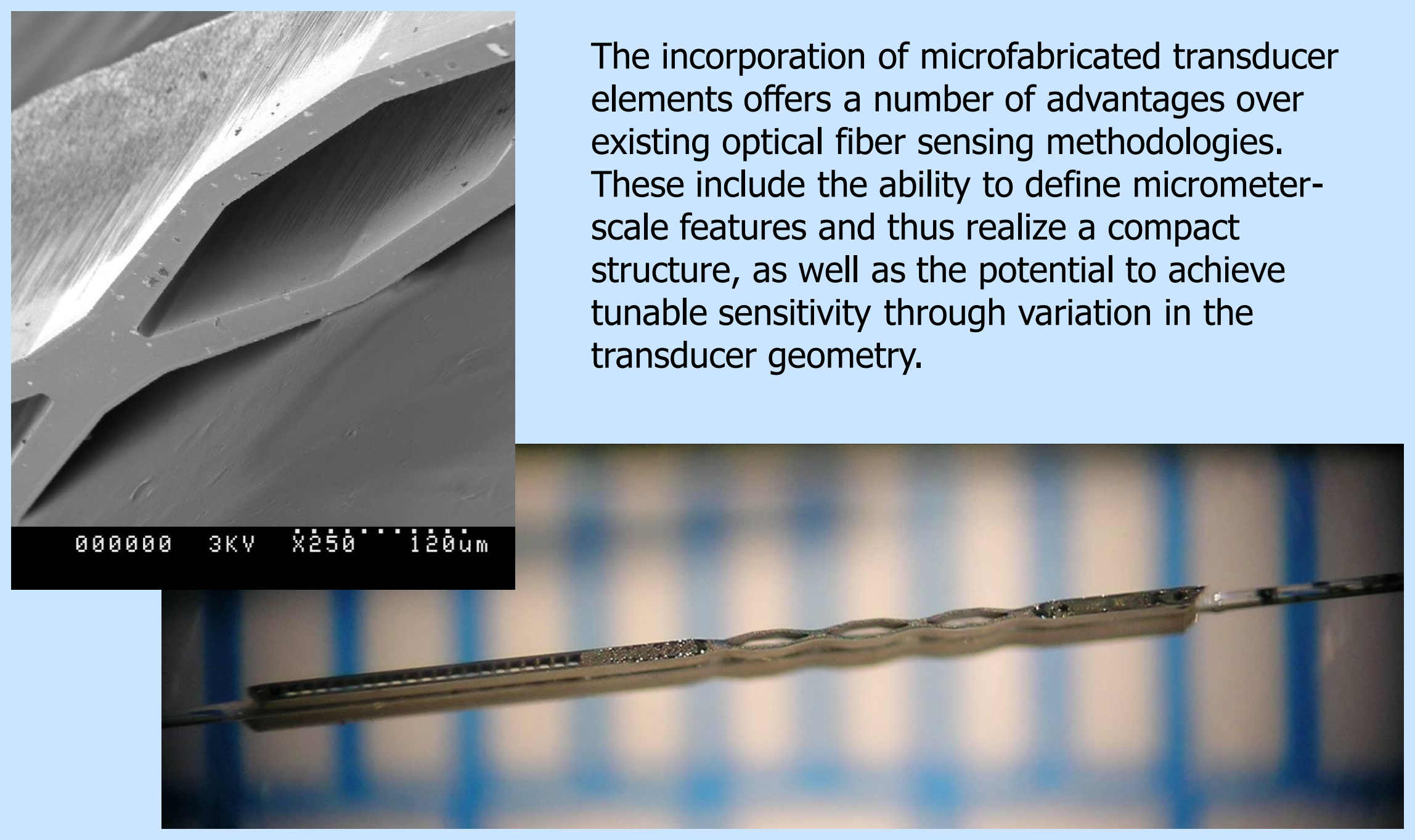


Single-mode 1550-nm fiber containing two FBGs; one grating is exposed to the load path and thus is used for force sensing, while the second grating is included for thermal compensation

Silicon Transducers

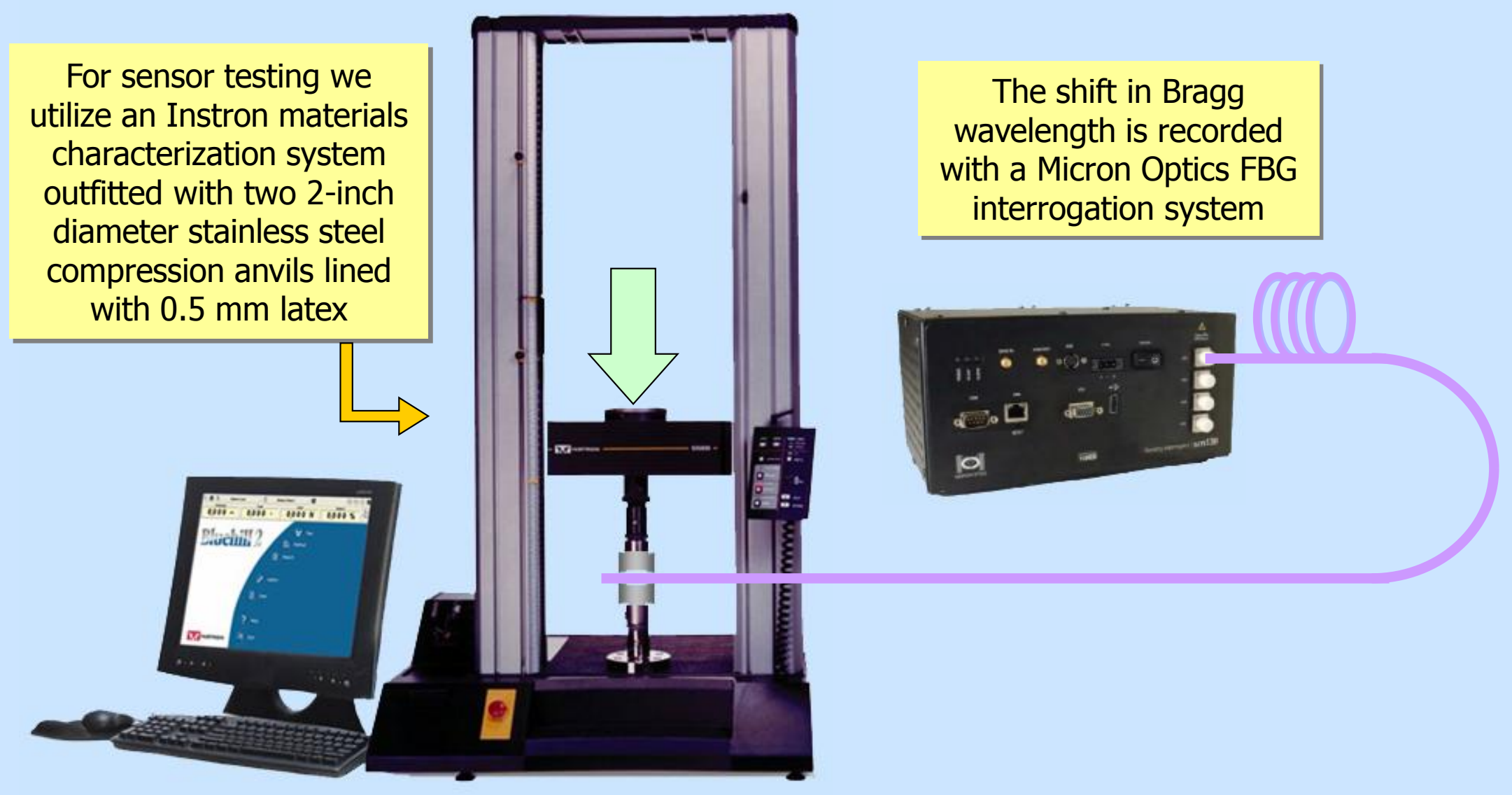


FEM simulation of the axial strain response: in this example 773 με is imparted to the fiber at 200 psi



The incorporation of microfabricated transducer elements offers a number of advantages over existing optical fiber sensing methodologies. These include the ability to define micrometer-scale features and thus realize a compact structure, as well as the potential to achieve tunable sensitivity through variation in the transducer geometry.

Characterization

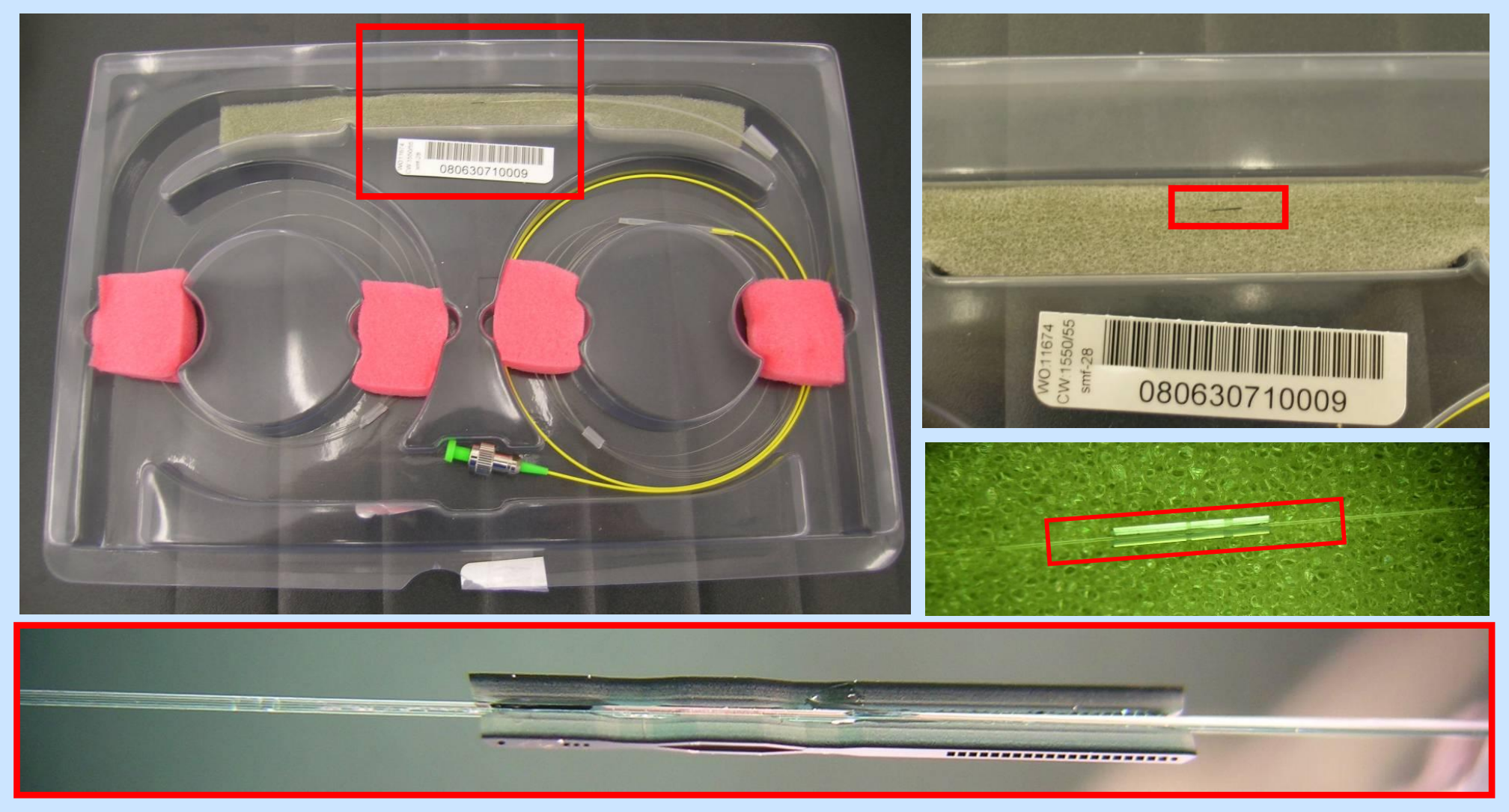


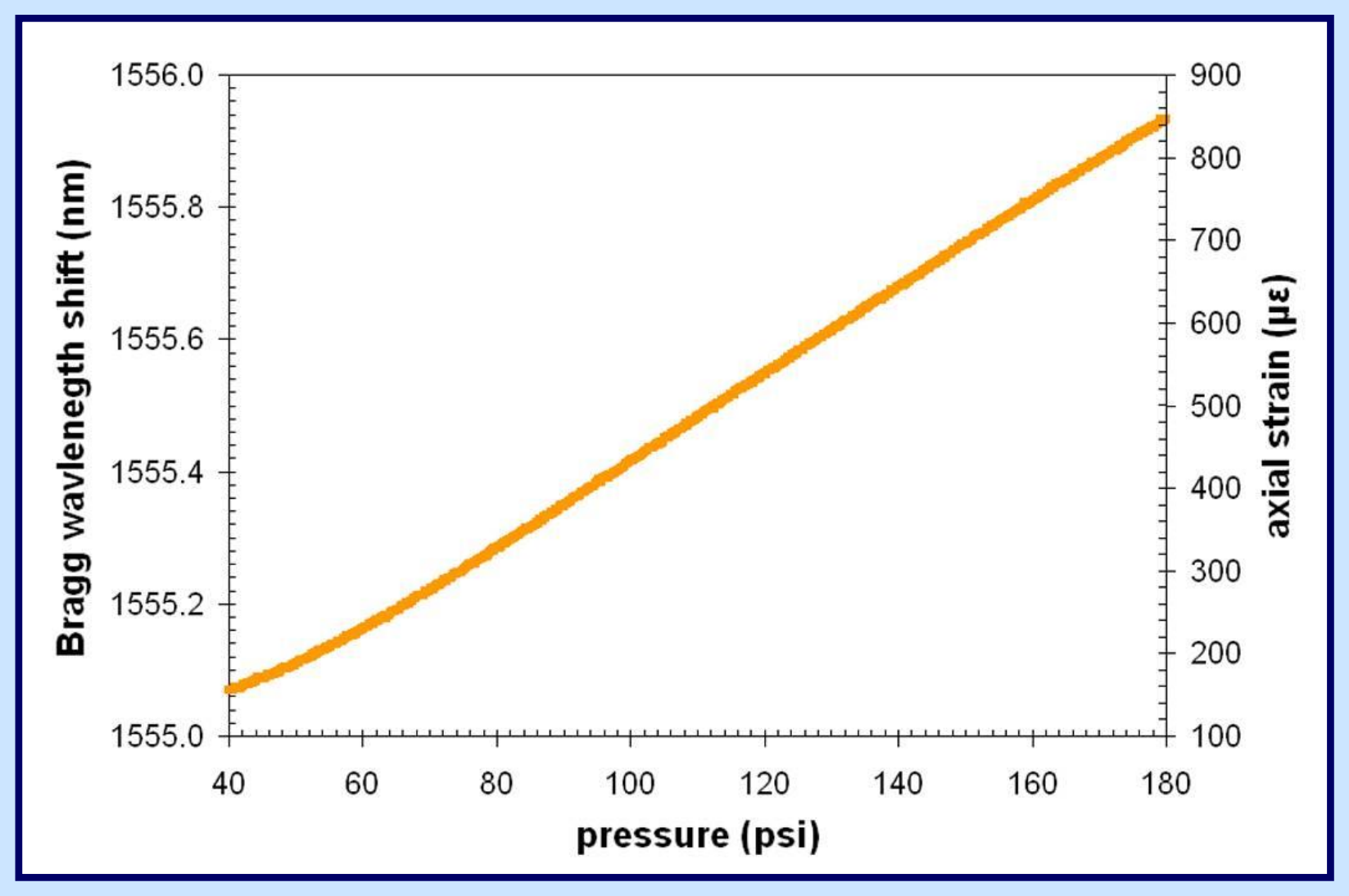
For sensor testing we utilize an Instron materials characterization system outfitted with two 2-inch diameter stainless steel compression anvils lined with 0.5 mm latex

The shift in Bragg wavelength is recorded with a Micron Optics FBG interrogation system

Given the transduction mechanism of the optical force probe—whereby a compressive load is converted to an axial strain in the fiber—it is possible to use a standard FBG readout system to measure the imparted load.

Because of the small thickness of the sensor when compared with the thickness of the compliant loading surfaces (140 μm thick OFP compared with 1 mm total latex thickness), the presence of the sensor in this configuration does not perturb the load path and the force is assumed to be uniform across the full area of the compression anvils.





Typical response of a single-transducer optical force probe under compressive loading. In this design (the same as that presented in the finite element model above) the sensitivity is 6.53 pm/psi (5.38 με/psi).