Chapter 4. Design and Fabrication of Multimode SCIIB Sensor Head

After we complete the design and implementation of the SCIIB sensor system comprising of the SCIIB Instrument Box and Data Acquisition System, another key work is focused on the design and fabrication of the sensor head which needs sophisticated fabrication technology to bring out the optimal performance of the total SCIIB sensor system.

The commonly used method by others to fabricate EFPI sensor heads is to use an epoxy to bond two fibers with their well-cleaved end-faces inserted into a glass capillary tube. However, the performance of the epoxy-based sensor heads is constrained by the physical and chemical property of epoxy. First, the maximum operating temperature of epoxy is very low — below 200 °C, which is not suitable for measuring high temperature such as 800 °C. Second, due to the coefficient of thermal expansion (CTE) of epoxy different from that of the fiber and the glass tube, when temperature fluctuates, the epoxy bonding point of the sensor head will produce undesired fluctuation caused by the elongation or shrinkage of the epoxy which may bring about error of measurement. Third, because of the manually bonding characteristic in epoxy-based sensor heads' fabrication process, it is very difficult for people to control the initial F-P cavity length and gauge length between the two bonding points.

Based on theoretical investigation and experimental probation, an innovative method named thermal fusion technique using a carbon dioxide (CO_2) laser for bonding is developed by the Photonics Lab at Virginia Tech to fabricate high-performance sensor heads. Furthermore, a set of accompanying quasi-automatic fabrication system for making EFPI fiber optic sensor heads is set up, which makes the fabrication process of sensor heads easier and more accurate to control the initial condition of the sensor heads. Since the thermal fusion technique implements the physical fusion of the optical fiber and the glass tube, there is little chance to introduce unpredictable factors at the bonding point like that of epoxy-based sensor heads. With this novel technique, we can fabricate high-performance SCIIB sensor heads to bring the performance of the total SCIIB sensor system into best play.

4.1 Design of Multimode Fiber-Based SCIIB Sensor Head

As discussed in Chapter 2, the design of the SCIIB sensor head primarily involves three key parameters' design issues — choices of initial F-P cavity length, initial gauge length and the initial operating point of the sensor head.

First, in our design of the multimode fiber-based SCIIB fiber optic sensor head, the choice of the initial sensor cavity length depends on the tradeoff between the coherence lengths of the two SCIIB channels and the fringe visibility discussed in Chapter 2. The optimal initial sensor cavity length should be chosen to allow the Narrow Band to generate an interference signal with a good fringe visibility, and at the same time to let the Broad Band output a non-interference signal. Based on the calculation and experimental results, for multimode fiber sensors, the initial sensor cavity length is often set between 7μm and 10μm.

Second, another key point we should notice is the relationship between the gauge length of the sensor head and the operating range of the sensor head. Because based on the principle of the SCIIB sensor system, we choose just about one-half of the interference fringe as the operating range of the sensor, thus the range of the F-P cavity length change must be within quarter of the operating central wavelength (e.g. 212.5nm for LED @ 850nm). Otherwise we can not get quantitatively one-to-one relationship between output optical intensity value and measured temperature value. According to Equation (2-17), we can figure out that longer the gauge length L, smaller the temperature change ΔT that can be detected when the largest F-P cavity length change Δs is fixed (e.g. 212.5nm for LED @ 850nm). In another word, if we want the sensor system to be used for measuring a large temperature change, the gauge length needs to be small enough for that big temperature change under the condition of fixed largest F-P cavity length change. For example, with the gauge length of 0.7mm the operating range of our SCIIB temperature sensor system is about 600 °C, and with the gauge length of 0.5mm the operating range of our SCIIB temperature sensor system is about 800 °C. Hence, commonly we say the value of the gauge length determines the value of the operating range of the sensor.

Third, the initial operating point of the sensor head needs to be precisely adjusted to the starting point of the linear portion of the interference fringe as discussed in Chapter 2. This allows the operating range of the sensor to cover the full linear range of the interference fringe to achieve the maximal operating capability of the sensor.

4.2 Sensor Head Fabrication System

In addition to design and implementation of the SCIIB sensor system, we also design and implement an automatic SCIIB sensor head fabrication system. Based on the thermal fusion technique we use in sensor head fabrication, the sensor head fabrication system consists of a carbon dioxide (CO_2) laser subsystem, a whitelight fiber optic interferometric subsystem and X-Y translation stage & piezoelectric (PZT) micro-motion positioning subsystem. This system realizes a quasi-automatic fabrication of a large quantity of high-performance SCIIB sensor heads at a low cost. For detailed information about the sensor head fabrication system, you can refer to Reference (27).

4.3 Fabrication of SCIIB Sensor Head

With the sensor head fabrication system, we can fabricate SCIIB high-performance sensor heads. First, buffer-removed fibers used to fabricate the sensor head are carefully cleaned using Alcohol and well cleaved using a fiber cleaver. The buffer-removed capillary tube is also cleaned and well cleaved to the desired length. Second, with the help of the microscope, the two pieces of fiber are then inserted into the capillary tube and clamped on the positioning stages by magnetic holders. By adjusting the micromotion stage system, the two pieces of fiber are moved to the preset positions where the desired initial sensor F-P cavity length is obtained. By moving the 2-dimentional translation stage underneath the micromotion stage system, the fiber and capillary tube assembly is brought to the center of the laser spot. The CO_2 laser emits light to heat the assembly with certain power level and duration controlled by the computer. We need to choose a proper power level and duration of CO_2 laser for good hermetically sealed sensor heads. After one side of the sensor head is bonded, the fiber and capillary assembly is then move to the other side to perform another same bonding process for the second bonding point. After completion of the second bonding process, a good sensor head is produced.

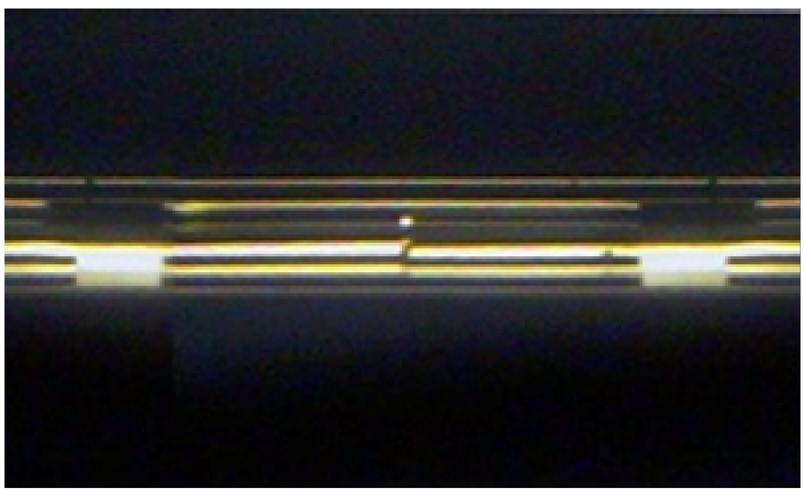

Figure 4-1. Microscopic photograph of the SCIIB sensor head

A photograph of a typical sensor head captured by the microscope is shown in Figure 4-1. From the picture we can clearly see the sensor head F-P cavity formed by the input fiber end face and reflecting fiber end face and the two bonding points. And the sensor head is sealed hermetically.