temperature and 800 degrees Celsius is made by matching the optical path lengths of the measurement and sensing arms at both temperatures. By marking the relative distance between the GRIN lens and mirror in the measurement arm for each case, the change in the optical path length of the sapphire is estimated to be approximately 0.318 centimeters. Despite a having maximum temperature 200 degrees Celsius greater than in the previous case, the difference in optical path length was 0.079 centimeters less than in the case case of a straight fiber. The microvoids expand with temperature at a faster rate than the sapphire, which results in the case of an optimally bent fiber having a shorter optical path length difference.

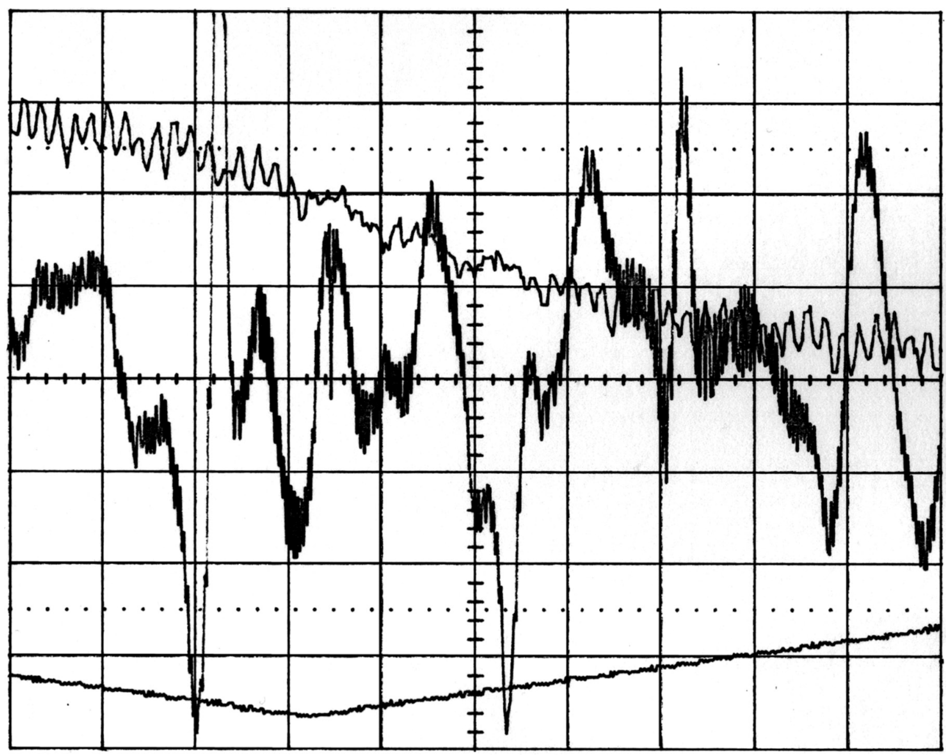

Figure 4.3.10: Test 2. Representative Intensity Variations Detected Between 700 and 800 Degrees Celsius While Using a Sapphire Fiber Sensing Head in the Modified WSFMI System.

4.3.5: High Temperature Test 3

A third test is performed with the goal of identifying and eliminating the fluctuations that arose at the end of the Test 2. In order to isolate the sensor from extraneous light from the glowing kiln, the sensing arm is first covered by a piece of hollow core fiber for protection, and then that is encased in a stainless steel tube. The sensor is protected by hollow core tubing because stainless steel oxidizes and flakes when subjected to temperature tests of this nature. The stainless steel tube is well supported by firebricks in the kiln. Tests show that the detected fringes possess better signal to noise ratios than in Test 2. This is thought likely to be due to the straighter orientation of the sensing region, which is a result of the influence of the long hollow core protection sleeve and stainless steel tube.

As the test is repeated, oscillations are again noted between 700 degrees Celsius and 800 degrees Celsius. The interface between the silica fiber and GRIN lens in the sensing arm is now considered to be the most likely source. It is noted that this assembly is in the path of warmed air, flowing through the hole in the kiln through which the sensor is inserted. It is hypothesized that this stream of air, which is expected to flow unpredictably in the large well ventilated room, is randomly heating, and thus unpredictably changing the index of refraction of the index matching fluid at the junction of the fiber and the GRIN lens. The fluctuation of the refractive index of the fluid causes the detected intensity variations. After plugging the hole in the kiln with insulating material, the fluctuations are reduced to barely noticeable levels. A plot at room temperature is shown in Figure 4.3.11 for a gap separation of approximately 1120 microns, and at 800 degrees Celsius in Figure 4.3.12 for a gap separation of approximately 1144 microns. In both figures, the middle trace is the detected interferogram and the bottom trace records the voltage driving the actuator. The top trace is detail of the fundamental fringe group associated with the sensing fiber endface in Figure 4.3.11 and with the reference fiber endface in Figure 4.3.12.

In Figure 4.3.11, the maximum signal to noise ratios of the fringe groups associated with reference and sensing fiber endfaces are 13.8 and 7.7 decibels, respectively. In Figure 4.3.11, the maximum signal to noise ratios of the fringe groups associated with reference and sensing fiber endfaces are 8.3 and 7.5 decibels, respectively.

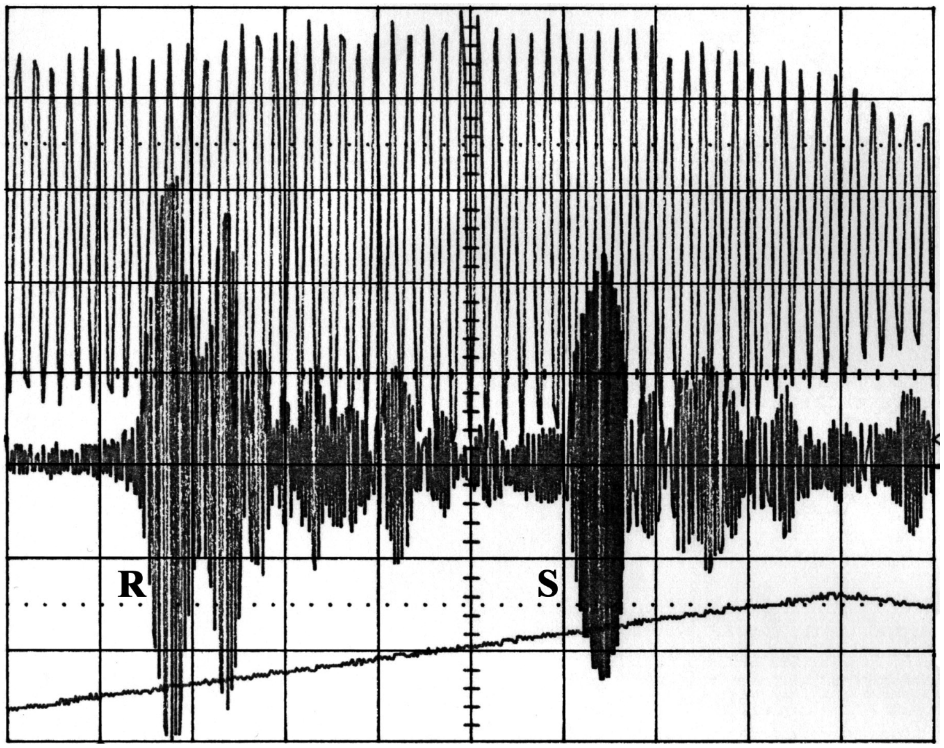

Figure 4.3.11: Test 3. Optimized Interferogram Obtained Using a Sapphire Fiber Sensing Head in the Modified WSFMI System at Room Temperature.

A possible solution to the problem of using index matching fluid to reduce reflections between the silica fiber and the GRIN lens in the sensing arm is to polish both the silica fiber and the GRIN lens at 8 degree angles and mate them as described in the case of the fiber collimator in the measurement arm. This method may not be ideal, because the elimination of index matching liquid at this interface will reduce the efficiency by which light is coupled between these two elements; it is vital to the operation of the WSFMI that as great a signal as possible be returned from the sensing arm. Having said this, it is unlikely that dispensing with the index matching liquid placed between the GRIN lens and the sapphire fiber reference fiber will have much of an effect. Currently, only a very thin layer of the liquid can be used, so its purpose as a coupling aid is doubtful and reflections from this interface are likely to be small.

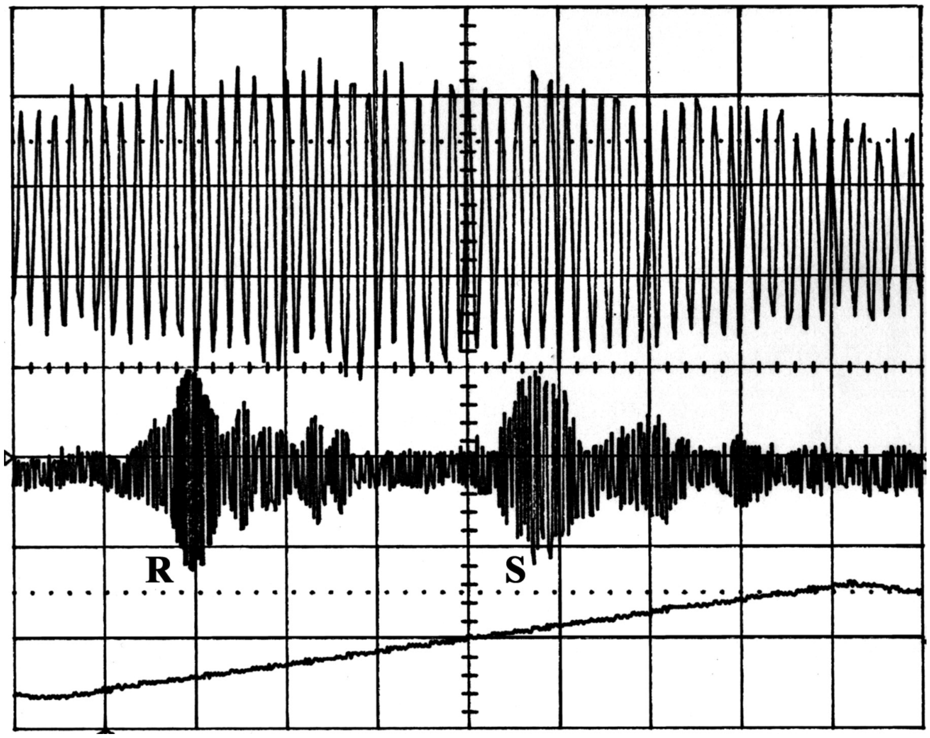

Figure 4.3.12: Test 3. Optimized Interferogram Obtained Using a Sapphire Fiber Sensing Head in the Modified WSFMI System at 800 Degrees Celsius.

In both this test and the previous, the sensor displays a greatly decreased sensitivity to the movement of people and objects in the immediate vicinity. The only vibrations that result in noise obscuring the detected signal arise from the slamming of the vestibule doors. In all of the high temperature tests, the fringe contrast decreased with increasing temperature. This is most likely due to scattering and absorption, as was reported by Dils.[11]

4.3.6 Use of the Modified WSFMI System to Support the Implementation of the Sapphire Fiber Extrinsic Fabry-Perot Interferometric Sensor

Though silica EFPI sensors are well understood and enjoy wide usage, the implemention of sapphire based EFPI sensors is not common because multimode effects and extremely small returned signal power render the signal unusable. It is theorized that the use of a GRIN lens mounted on a three axis positioner to direct collimated light into the sapphire fiber will improve the performance of the extrinsic Fabry-Perot interferometer (EFPI). It will increase the power of the returned signal by reducing the amount of energy coupled into the lossy higher order modes, and it will also reduce the multimode effects by exciting mostly the lower order modes, with the fundamental mode being dominant.

The modified WSFMI setup is adjusted to support an EFPI sensor by removing the measurement arm and using a laser diode (LD) as a source. The operation of an EFPI sensor depends on the interference of the two beams reflected from the EFPI sensing head, one from each endface. Because of this, the measurement arm is not needed and an LD is substituted for the superluminescent light emitting diode (SLED) because its longer coherence length will increase the sensing range of the sensor.

In each of the following experiments, the WSFMI setup is used to make the fundamental mode the dominantly excited mode, and then the measurement arm is removed from the system. A group of EFPI fringes is created by quickly moving the sensing fiber from a position in which it touches the reference fiber to one a few millimeters away. A sample EFPI characteristic is shown in Figure 4.3.13. The fringes, seen in the detail of the EFPI characteristic, are not smooth because the movement of the motorized stepper motor, which is used to adjust the gap length, is not smooth. The maximum amplitude and length of this group of fringes is recorded. The GRIN lens is then misaligned in several 1 micrometer steps. For each step, the length and the maximum amplitude of the EFPI fringe group is recorded.

With increasing misalignment, the EFPI fringe groups decrease in amplitude and length. The signal decreases into unusable levels after being misaligned laterally by 5 micrometers, as shown in Figure 4.3.14. The GRIN lens is then realigned using WSFMI system and the process detailed above is repeated using a LD as the source. It is found that the EFPI fringes generated with the GRIN lens in the aligned position do not necessarily possess the greatest possible amplitude and length, but that the signal is always detectable.

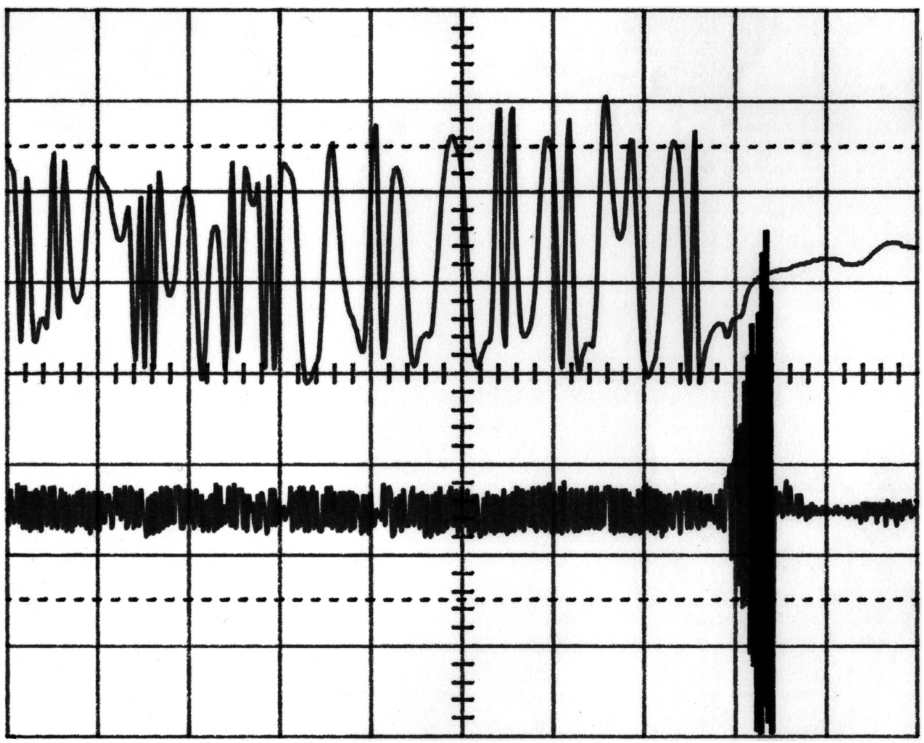

Figure 4.3.13: Sapphire Fiber EFPI Fringes Generated After Using the Modified WSFMI System to Align the Sensing and Reference Fibers.

The spatial coherence of the LD is responsible for the fact that the attempt to optimize the EFPI characteristic fringes, through the alignment of the GRIN lens using the WSFMI process, has a very slight chance of total success. The LD has a higher spatial coherence than the SLED. When the modes propagating in the fiber mix due to perturbations and add constructively, the EFPI characteristic fringes will be less than optimal in amplitude