In magnetically confined fusion (MCF), resistive bolometers are conventionally used for the detection of the plasma radiation helping to understand heat exhaust scenarios. However, the performance of resistive bolometer experiences unavoidable degradation in the practical applications due to the strong electromagnetic interference present in MCF systems. The limitations of the resistive bolometer motivate us to develop a novel fiber-optic bolometer instead of the original resistive bolometer due to the inherent immunity of optical fiber to the electromagnetic interference.

To develop a fiber-optic bolometer, we first theoretically study the spectral characteristics and noise performance of wavelength-interrogated fiber-optic sensors based on an extrinsic Fabry-Perot (FP) interferometer formed by thin metal mirrors. The fiber-optic bolometer is indeed a fiber-optic extrinsic FP interferometric temperature sensor. We develop a model and use it to analyze the effect of key sensor parameters, including the beam width of the incident light, the metal coating film thickness, the FP cavity length, and the wedge angle of the two mirrors, on the visibility and spectral width of the sensors. Through Monte Carlo simulations, we obtain an empirical equation that can be used to estimate the wavelength resolution from the visibility and bandwidth of reflection fringes. The work provides a useful tool for designing, constructing, and interrogating high-resolution fiber-optic extrinsic FP interferometric sensors with metal mirrors.

Based on the theoretical analysis mentioned above, we demonstrated a low-finesse fiber-optic silicon FP temperature sensor with high speed by considering the end-conduction effect, which refers to the unwanted heat transfer between the sensing element and the fiber stub delaying the sensor to reach
thermal equilibrium with the ambient environment. The sensor is constructed by connecting the narrow edge surface of a thin silicon plate to the edge of the microtube attached to the fiber tip. Compared with the sensor of traditional design, the sensor of the new design shortened the characteristic response time in still air from 83 ms to 13 ms and improved the sensor resolution by a factor of 12, from 0.15 K to 0.012K. Wavelength tracking method is commonly used for low finesse fiber-optic FP interferometric sensors due to its high resolution and straightforward implementation. We report the observation of random spurious jumps in a commonly used wavelength tracking method based on curve fitting. We analyze the origin of the spurious jumps through Monte Carlo simulations where the fringe valley positions are obtained using polynomial curve fittings. The simulation results show that the spurious jumps arise mainly from the systematic errors of the curve fitting function for modeling the sensor spectrum and manifested by the changes in the pixel set for curve fitting. To eliminate these jumps, we propose a modified correlation demodulation method where the information of the measurand is obtained through the correlation between the measured sensor spectral frames and a sufficiently large number of calibrated frames of the sensor over the measurement range. The simulation and experimental results show that the modified correlation method can eliminate the spurious jumps encountered in the regular wavelength tracking. The resolution of the method is also studied and compared with the curve fitting method.

In addition to the low-finesse fiber-optic bolometer, we demonstrate a fiber-optic bolometer based on a high-finesse silicon FP interferometer. The silicon FP interferometer absorbs and converts the incident radiation into temperature variations, which are interrogated by the shift of the reflection fringes of the FP interferometer. The FP interferometer is a silicon pillar with one side coated with a high-reflectivity dielectric mirror and the other side coated with a gold mirror. A reference bolometer was used to effectively reduce the common noises from the laser drift and the ambient temperature variations. Experimental results show that our new fiber-optic bolometer has a noise equivalent power density of 0.27 W/m², which is comparable with the conventional resistive bolometer. Taking advantage of this new fiber-optic bolometer, we then carefully study the influences of mechanical vibration and static or quasi-static magnetic field, which can present in the practical applications, on the noise performance of bolometer. It is found that both the vibration and the magnetic field could cause large fluctuations in the demodulation results of bolometer measured in a stable environment due to the birefringence of the silicon FP interferometer. To mitigate the birefringence effects, we demonstrated two effective methods: polarization maintaining fiber replace the single-mode fiber, and polarization scrambling. Experimental results show that these two methods have a good performance in mitigating the birefringence effects. These results show that the fiber-optic bolometer is a promising technology for plasma diagnosis in MCF systems.