All-fiber, high-accuracy reconstructive spectrometer based on differential polarization division multiplexing

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S1. Stability of the speckle spectrometer

Long MMFs are naturally vulnerable to environmental disturbances. To mitigate these disruptions, we placed the MMF within a dry chamber with a constant temperature (temperature variation: ±0.2℃), tightly winding the fiber around a spool and securing the free end with a fixture. We recorded the MMF's output speckle every two minutes over a period of 100 minutes. The speckle recorded at each interval was compared to the initial reference speckle to compute the Pearson correlation coefficient (as described in Equation (S1)). Due to the sealed and thermally insulated setup of the MMF, the speckle's correlation coefficient remained above 0.96, as illustrated in Fig. S. 1.

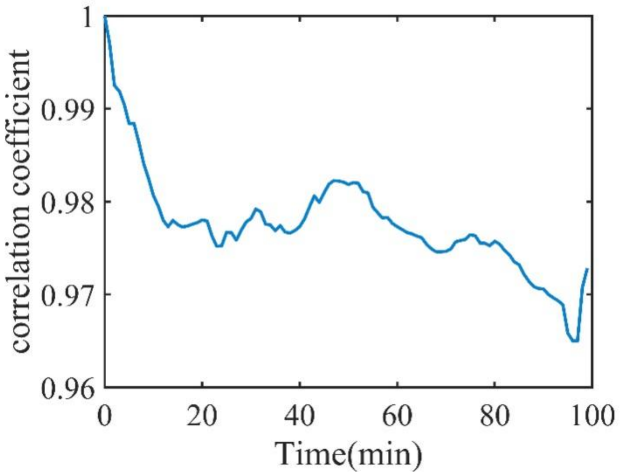

Figure. S. 1. The speckle stability of our proposed spectrometer.

The Pearson correlation coefficient is defined as:

$$\rho[I(t_0), I(t)] = \frac{\sum\sum[I(t_0) - \overline{I(t_0)}][I(t) - \overline{I(t)}]}{\sqrt{\{\sum\sum[I(t_0) - \overline{I(t_0)}]^2\}\{\sum\sum[I(t) - \overline{I(t)}]^2\}}} \qquad \text{(S.1)}$$

Where $I(t_0)$ is the reference speckle intensity at 0-minute and $I(t)$ is the speckle intensity at the time of t. Their mean values are marked by the overbar.

S2. Spectral resolution enhancement of DPDM

As shown in Fig. S. 2, we calculated the spectral correlation curve of the speckles for 100-m fiber and 1-m fiber respectively. 100-m MMF has a half width at half maximum (HWHM) about 2 pm, which can be used as an estimate of system resolution. But in fact, the resolution that the algorithm can identify is usually higher than this value [1]. Unfortunately, the highest resolution achievable with our current tunable laser used for calibration is 1 pm, thus we cannot verify a resolution higher than 2 pm in spectral measurement. The HWHM of the 1-m MMF is about 100 pm, which has enough space to investigate resolution improvement. Thus to evaluate the capability of DPDM in improving spectral resolution, we designed an experiment by using the 1-m MMF. As illustrated in Fig. S. 3, we analyzed a dual-peak signal separated by an interval of 10 pm, which is a tenth of the previously estimated resolution (100 pm). It can be seen that without employing the DPDM scheme, distinguishing between the two peaks becomes very difficult. As shown in Fig. S. 3(a) and (b), the difference between the reconstructed noise values and the reconstructed signal values is less than 3 dB, which may result in significant ambiguity. While with DPDM, the reconstructed spectrum better aligns with the original shape, suggesting that DPDM holds significant promise for enhancing spectral resolution.

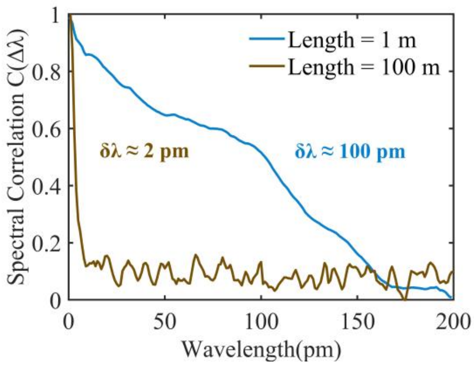

Figure. S. 2. Spectral correlation curve of the speckles for 100-m fiber and 1-m fiber.

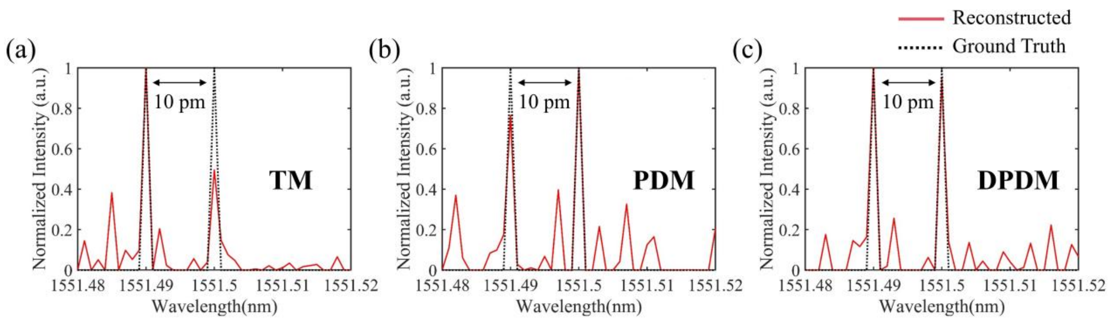

Figure. S. 3. Reconstruction results when employing (a) TM, (b) PDM, and (c) DPDM scheme, respectively. The reference spectrum is a dual-peak signal with an interval of 10 pm.

Reference

1. S. Xu, J. Zhang, J. Cheng, and J. Dong, "Integrated spatial-temporal random speckle spectrometer with high resolution in the C-band," Photon. Res. **12**(7), 1556 (2024).