Supporting Information

Universal measurement system for optical fiber diameter based on mode interference

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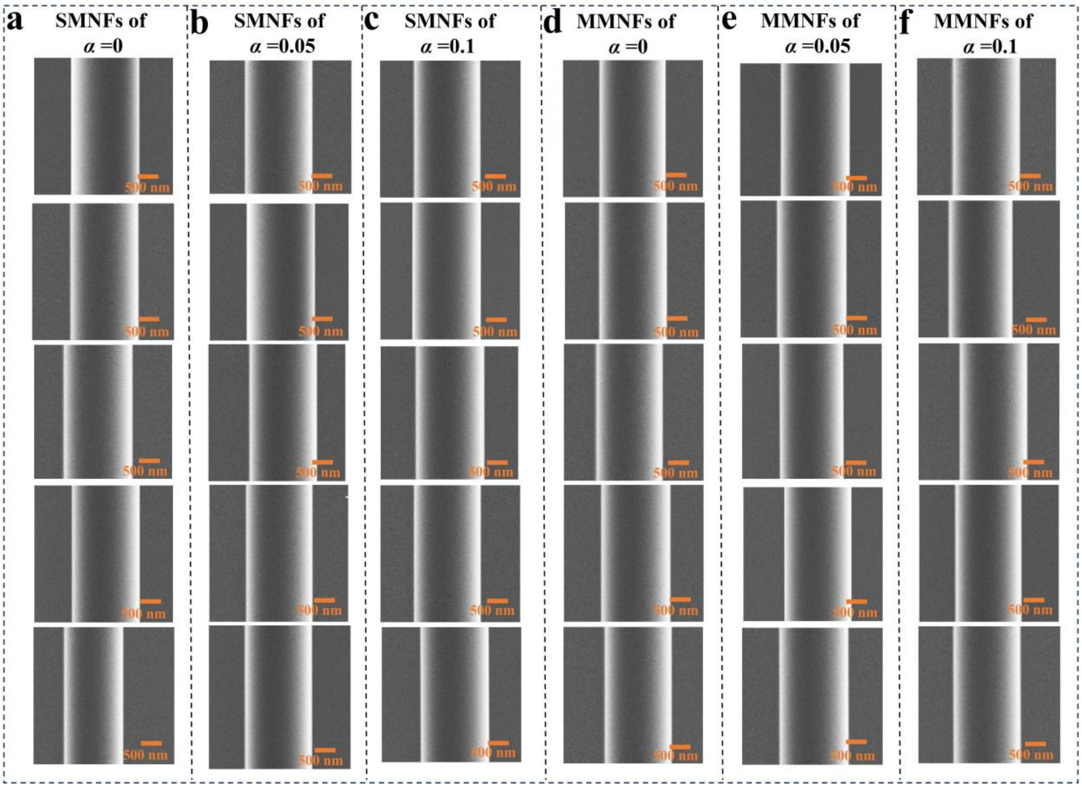

Fig. S1. SEM results of SMNFs and MMNFs fabricated with different taper profiles for a target waist diameter of 1700 nm. **a-c** SEM images of SMNFs with linear modification factors $\alpha = 0$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. **d-f** SEM images of MMNFs with linear modification factors $\alpha = 0$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. All measurements were performed under the same magnification.

Our system enables the fabrication of MNFs with specific target diameters and various taper profiles, suitable for applications in fields such as quantum optics and nonlinear optics, where the fiber diameter is highly critical. To demonstrate the superior performance of our system, we set target diameters of 1700 nm, 1200 nm, and 700 nm, respectively, and fabricated both SMNFs and MMNFs with different shapes.

The actual waist diameter of the samples were measured by SEM and compared with the target diameter. Prior to SEM characterization, the fiber surface was coated with a precise 2 nm conformal gold film to prevent charge accumulation. The deposition was performed using a high-vacuum magnetron sputtering coater (GVC-2000TD), which ensures excellent step coverage. Moreover, any potential measurement uncertainties in the fiber diameter arising from the slight surface non-uniformity of the sputtered gold film were effectively mitigated through statistical averaging. To further enhance conductivity and obtain images with sufficiently clear edges, the ends of the fibers were securely fixed to the substrate using conductive colloidal silver. Because the colloidal silver paste is highly volatile, the prepared samples were strictly left to rest in a dust-free, well-ventilated environment for over 48 hours after solidification before introducing them into the SEM vacuum chamber.

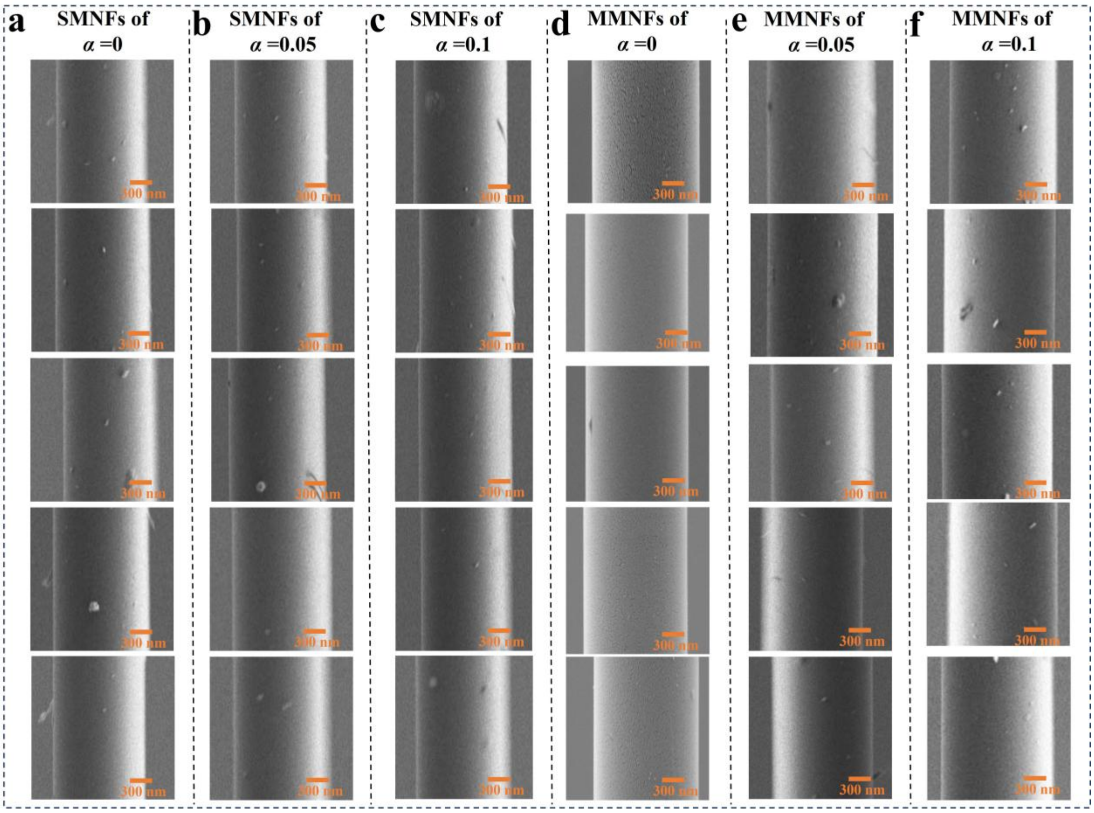

Fig. S2. SEM results of SMNFs and MMNFs fabricated with different taper profiles for a target waist diameter of 1200 nm. **a-c** SEM images of SMNFs with linear modification factors $\alpha = 0$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. **d-f** SEM images of MMNFs with linear modification factors $\alpha = 0$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. All measurements were performed under the same magnification.

During SEM characterization, the thinnest region along the MNF waist was identified and designated as the spatial origin. Subsequently, a total of 7 independent localized diameter measurements were systematically acquired: one precisely at the origin, and six additional measurements distributed symmetrically at 20 μm intervals along the longitudinal axis (i.e., at ±20, ±40, and ±60 μm). Representative high-resolution SEM micrographs captured at the origin of each sample are presented in Figs. S1, S2, and S3. It should be noted that the minor surface cracks observed in the micrographs originate from the inherent stress-induced micro-fissuring of the 2nm sputtered gold film, while the sparse particulate features are attributed to ambient environmental dust. To ensure rigorous visual and metrological comparability, all SEM images of MNFs sharing the same target diameter were acquired at identical magnification settings. Furthermore, each column of SEM images (ordered from top to bottom) directly corresponds to the respective MNF samples presented in Fig. 5 of the main manuscript (ordered from left to right).

To strictly eliminate subjective bias during diameter extraction, a quantitative grayscale gradient analysis was implemented. As illustrated in Fig. S4, the high-definition SEM micrographs were imported into the scientific image analysis software ImageJ. The determination protocol was executed as follows: First, the spatial scale of each image was precisely calibrated using the SEM's internal high-resolution scale bar. Next, a transverse line profile, strictly orthogonal to the fiber axis, was drawn at each designated measurement location to extract the transverse grayscale intensity distribution. Rather than relying on visual estimation of the fiber boundaries, we mathematically defined the two physical edges of the MNF by calculating the absolute value of the first spatial derivative (i.e., the absolute grayscale gradient) of the intensity profile. The precise pixel coordinates corresponding to the two maximum peaks of this absolute gradient curve were algorithmically identified. The localized physical diameter of the MNF was then calculated by measuring the spatial interval between these two gradient peaks. Finally, the representative waist diameter of the sample was determined by averaging the diameters extracted from the 7 spatial locations, with the measurement uncertainty rigorously expressed as the standard error (SE) of these 7 independent data points.

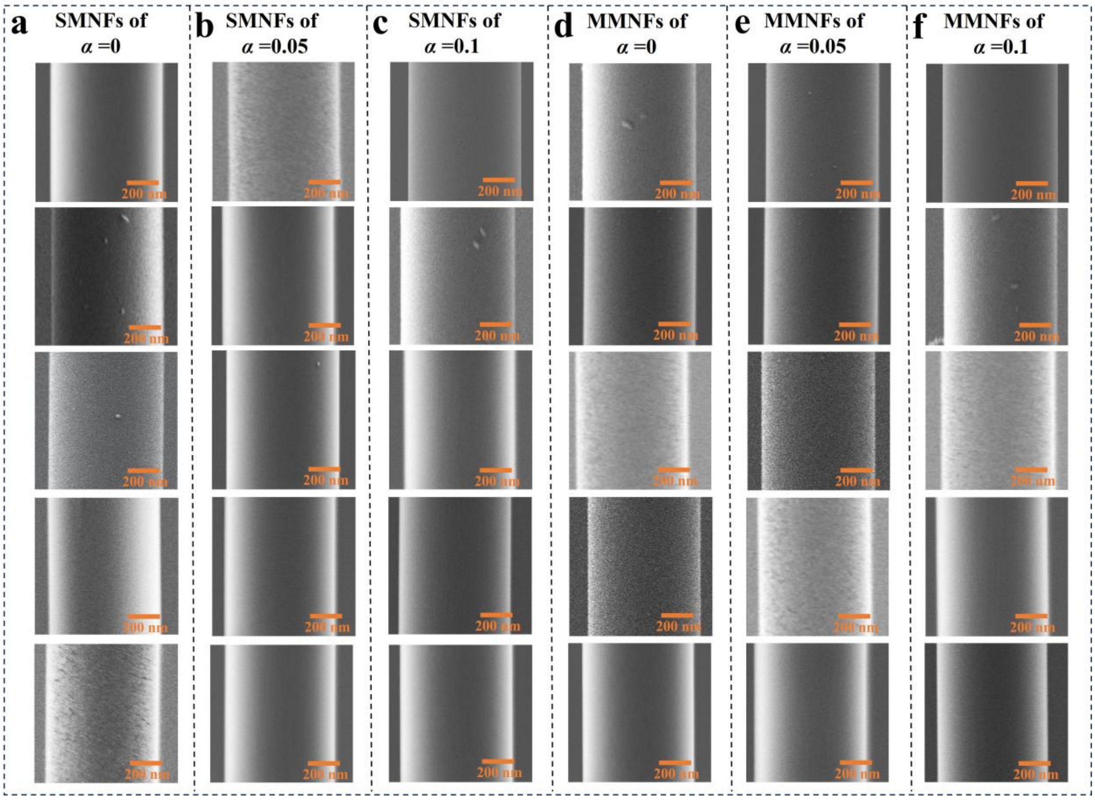

Fig. S3. SEM results of SMNFs and MMNFs fabricated with different taper profiles for a target waist diameter of 700 nm. **a-c** SEM images of SMNFs with linear modification factors $\alpha = 0$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. **d-f** SEM images of MMNFs with linear modification factors $\alpha = 0$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. All measurements were performed under the same magnification.

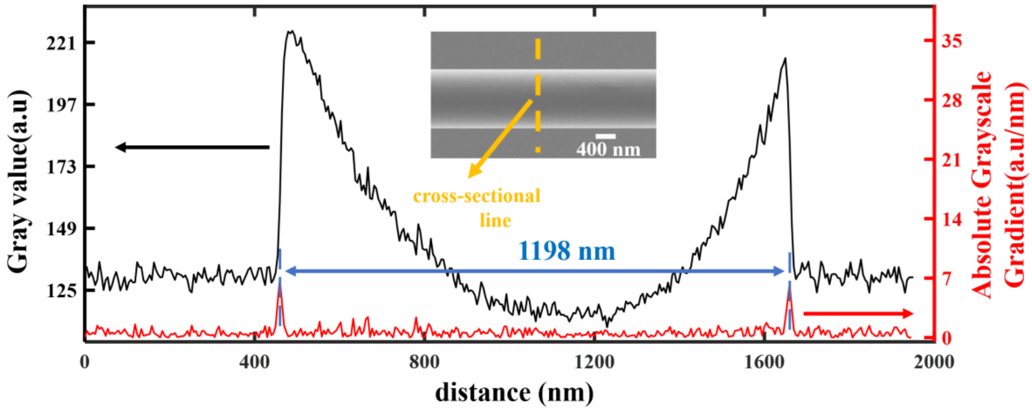

Fig. S4. Determination of the MNF diameter via quantitative image analysis. The inset displays a high-resolution SEM micrograph of the fabricated MMNF(target diameter=1200 nm, α=0), with the yellow dashed line indicating the exact location of the transverse cross-section. The black curve (left axis) represents the transverse grayscale intensity profile (gray value) extracted along this cross-sectional line. The red curve (right axis) plots the absolute first derivative (absolute grayscale gradient) of the intensity profile. The physical boundaries of the fiber are defined by the spatial positions of the two maximum gradient peaks. The physical distance between these two peaks yields an objective and highly accurate diameter measurement (e.g., 1198 nm as shown).