Abstract—We present a simple robust local electrical fusing approach for microknot resonators using a two-probe technique. These devices exhibit significantly improved optical performance and mechanical stability, and can be applied in next generation optomechanical sensors.

Keywords—microknot resonators; fiber fusing techniques; microfiber ring resonators

I. INTRODUCTION

Optical microknot resonators (MKRs), defined locally on optical fiber tapers [1], find use in various applications, including photonic filters, lasers, optomechanical light-matter interaction devices, and various sensing elements [2,3]. Typically MKRs are produced manually via looping and pulling on a microfiber taper [1]. This makes the MKRs tuneable in diameter, via pulling force, but also amenable to low performance in terms of resonance depth and width, and fragile mechanically. Therefore, an existing challenge in ambient deployment of MKR structures relates to post-preparation treatment [4].

Many fusing techniques in optical fibers have been developed in the past, including with optical [4–6], mechanical [7], or electrical [8] approaches.

In this paper we apply our two-probe localized heating technique for MKR fusing, with which significantly improved optical performance and mechanical stability have been consistently achieved. In-situ, as well as transferred devices, have been operated with low losses. These devices with improved optical and mechanical characteristics can be harbored in next generation sensors, actuators, and optomechanical applications incorporating MKR structures.

II. EXPERIMENTAL SETUP

Tapers defined within single-mode low-loss fused silica fibers (wavelengths of operation 1.5-1.6 μm), 4-8 mm in length and 3-6 μm in minimum diameter, with high uniformity, were produced using the AFL Lazermaster LZM-100 splicing system [4]. The experimental setup is shown in Fig.1. Figure 1 (a) introduces schematics of the fusing system components, including optical (red solid lines) and electrical (blue dashed lines) lines. Figure 1 (b) shows the MKR manipulation chamber center, including a microscope station used for monitoring the MKR and positioning of both of the probes. Figure 1 (c) shows a magnified image of the MKR, together with the pair of electrical probes used for its manipulation, in contact near the coupling area. Both of the probes are sequentially displaced to the coupling points P1–P4, within the coupling area. After their contact, the fusing voltage in the range 2–10 V (direct current) has been applied. This effectively generates an electrical Joule heater between the metallic probe tips, where local heating is attained at the tip edges. A tapered straight fiber was wound into a knot and placed inside the setup. Next, the knot was stretched to diameters in the range 0.5–1 mm, following introduction of the electrical probes in contact within the knot coupling area. The points of interest denoted P1–P4 (see Fig.1 (c)). P1 and P2 are the boundaries of the coupling area, whereas P3 and P4 are chosen in between P1 and P2. The transmission spectra of the fused and unfused MKR are shown in Fig. 1 (d). The periodic MKR resonances enable experimental determination of the free spectral range (FSR), Q-factor and dynamical range (DR).

![Experimental setup](image-url)
From the output transmission spectra we derive the FSR, Q, and DR parameters in a given MKR. An approximate threefold increase in the DR is systematically observed, which remained stable over at least three days.

To test the fused MKR mechanical stability, we prepared both a fused and an unfused microknot in parallel, and then performed a pulling test on both of them. A stable locally fused MKR should maintain its shape and constant diameter even when pulling, followed by a sudden breakage when the pulling strain surpasses critical value. An unfused MKR will shrink continuously and break after reaching its minimum diameter. Data derived from spectra sampled during the pulling test is presented in Fig. 2.

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**Fig. 2.** Pulling test. (a): Free spectral range as a function of pulling. (b): Quality factor as function of pulling. Black squares represent data for an unfused knot, and red circles are for electrically fused knot. Breaking points are denoted in both cases with black circles.

We monitored the FSR and Q-factor in both of the MKRs. The FSR of the fused knot, being related to the knot size, remained fairly stable at the pulling strain level of (0–5) %, where after slight jump at 5%, the knot was subsequently broken. FSR in the unfused knot grows exponentially and continuously, with breakpoint being reached when pulling strain reached 30%. In turn, the Q-factor of both fused and unfused microknots gradually decreases, and the MKRs were broken at 5% and 30% respectively. This result proves that local electrical fusing improves the MKR shape stability, similarly to other fusing techniques [4]. Monitoring the MKR parameters in real time we have observed up to threefold instantaneous DR enhancement.

The other noticeable trend we observe is the improved phase stability caused by electrical fusing. The unfused MKRs phase behavior is strongly dependent on ambient conditions, such as sliding of both sides of the taper, which affect on circular MKR profile unpredictably. In some instances of the unfused MKR, we have observed an accumulating phase drift rate of 0.016 degrees per minute, which was completely eliminated following MKR fusing. We have also succeeded in easily transferring the fused MKR to a glass substrate.

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**IV. Conclusion**

In this paper we presented a simple and robust approach for local electrical fusing of microknot resonators using a two-probe technique. The e-fusing possesses a good reproducibility on the MKRs of diameter (0.4–1) mm. Fused MKRs demonstrate superior optical performances and mechanical strengths compared to unfused MKRs, that are tantamount to sensing, filtering and optomechanical coupling elements, where MKRs can find suitable applications. We found that a consistently above threefold dynamical range enhancement can be achieved, which remained stable in time over several days, in e-fused MKRs. Moreover, fused MKRs have maintained phase stability, as opposed to the unfused knots that exhibited random phase drift. Pulling tests proved that e-fusing improves mechanical strength in the MKR, providing it with transferability that can be harbored in next generation optical sensors, actuators, and optomechanical applications incorporating MKR-assisted micro-structures, taking advantage of this simple and robust fusing technique.

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**References**


