Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Self-assembled fiber Mach-Zehnder interferometer based on liquid crystals

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Figure S1: Fabrication process of the LC-based fiber MZI.

As shown in Figure S1 (a), the LC-based fiber MZI is fabricated by six steps method. Firstly, the microtubule is spliced with a SMF_1 by fusion splicer (Fujikura FSM-100P+, Japan) without offset after the automatic alignment (Step i). The inner and outer diameters of the microtubule are 50 μm and 125 μm, respectively, and the cross-section as shows in the Figure 5(b). The microtubule is then cut to leave a 300 μm length between the splicing point and the microtubule ending (Step ii). In our experiment, we also selected 200 μm and 400 μm length of microtubes, but no obvious interference spectra were observed from the device. For the 200 μm microtubule, the untwisted LC area is too short as the length of the twisted LC area is about 140 μm, resulting in the free spectrum range (FSR, $\lambda^2/(\Delta nL)$) of the LC-based fiber MZI beyond the range of the spectrometer. For 400 μm microtubule, the light is scattered within liquid crystal and disrupted the formation of the interference spectrum as the length is too long. In the step iii, the microtubule is spliced with a SMF_2 by fusion splicer with a 5 μm position offset along Y direction relative to SMF_2 after the automatic alignment. In the experiment, the position offset of 5μm conducive to forming interference fringe for the MZI. The spliced sandwich structure of SMF_1-microtubule-SMF_2 is shown in Figure 5(c). The side of the microtubule is etched by a femtosecond laser (central wavelength is 795 nm, Spectrum Physics Co. Ltd) with a groove having a 300 μm length, 50 μm width and 87 μm depth, respectively, thus forming an exposed-core groove (ECG) by the microtubule and fiber-end (Step iv). The side and cross-section of the ECG structure after laser processing are shown in Figure 5(d) and Figure 5(e), respectively. Then, the inside wall of the ECG coated with vertical PI after cleaned by ethanol and deionized water (Step v). Finally, the ECG is filled with LC, and the LC-based fiber MZI is fixed on the glass slide with glue to protect ECG structure (Step vi).

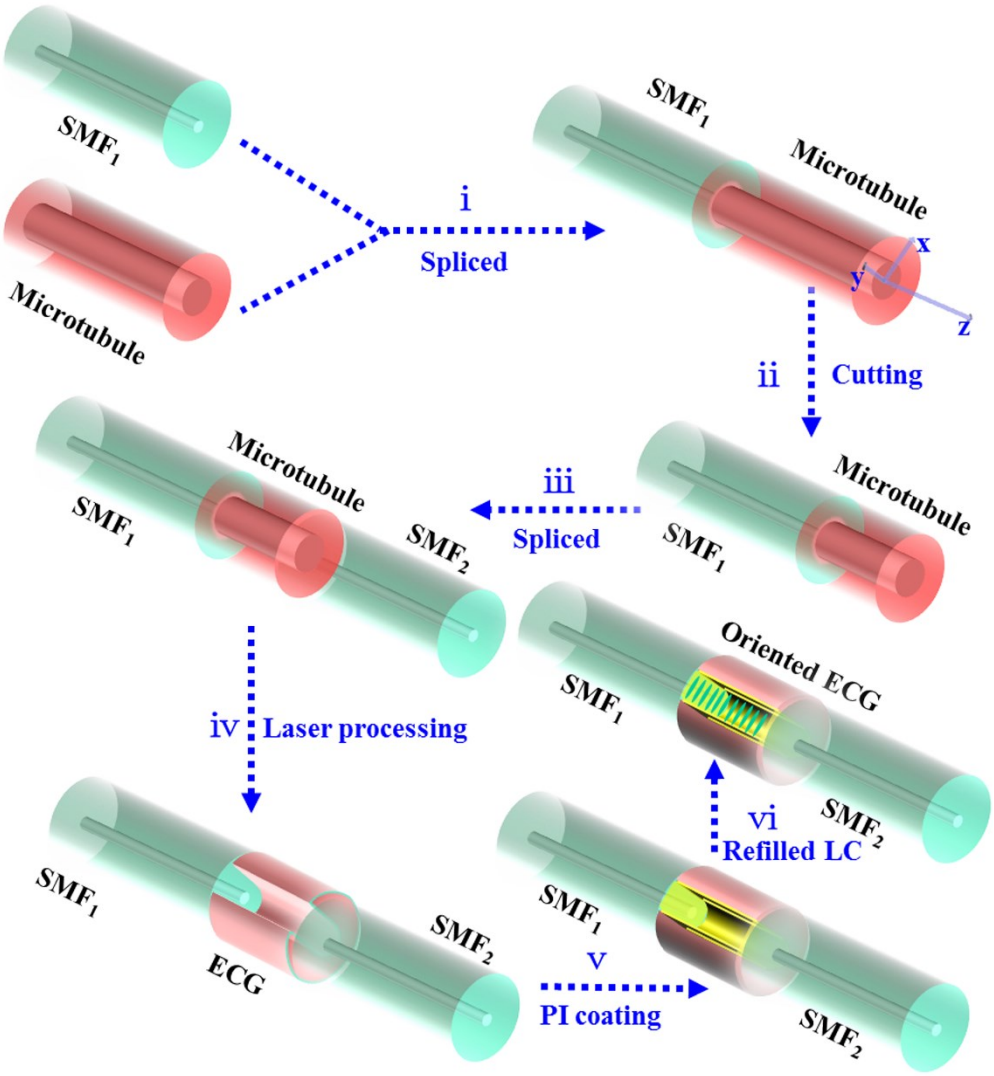

Fig. S1. (a) The fabrication process of the MZI. (i). The microtubule is spliced with a SMF_1 by fusion splicer. (ii). The microtubule is cleaved by fiber cutter to a certain length. (iii). The SMF_1-microtubule is spliced with SMF_2 by fusion splicer. (iv). The structure of the ECG is prepared by femtosecond laser. (v). A PI film is coated on the inside wall of the ECG. (vi). The structure of the ECG is filled with LC.

Figure S2: The liquid crystal transition after adsorbing VOC vapor.

Figure S2 (a) depicts the detection process of the liquid crystal (LC) transition as increasing the concentration of ethanol vapor. The LC-1001 is filled into the LC cell with vertical orientation. The cell thickness is 50 μm. Then, the ethanol cotton is close to the LC cell, and release vapor into LC. Finally, the cotton is removed from the LC cell. Figure S2 (b-d) show the device images observed under a polarizing optical microscope, where the directions of polarizer and analyzer are represented by P and A, respectively. It can be seen from the Figure S2 (b) that the device is in a dark state. The LC molecules are oriented perpendicular to the substrate. In the Figure S2 (c), we can clearly see that the device shows dark to bright transition when the ethanol cotton is close to the LC cell. The dark and bright transition indicates that the alignment of the LC molecules is reoriented in the LC cell. In addition to becoming brighter, the

device appears rainbow-colored, due to the different distance between LC molecules and ethanol cotton with different vapor concentrations. According to the Michel-Levy interference color chart (Figure S3), the appearance of rainbow colors indicated that the different birefringence of the LC as the different concentration of the VOC vapor in the LC cell. For the LC-based fiber MZI, the λ_m represents the attenuation peak wavelength and can be as $\lambda_m=2\Delta nL/(2m+1)$, where the Δn is the birefringence of the LC. The attenuation peak wavelength λ_m will be shifted as changes the Δn of the LC. In the Figure S2 (d), we can clearly see that the device shows bright to dark transition when the ethanol cotton is removed from the LC cell. The LC molecules are oriented to perpendicular the substrate again.

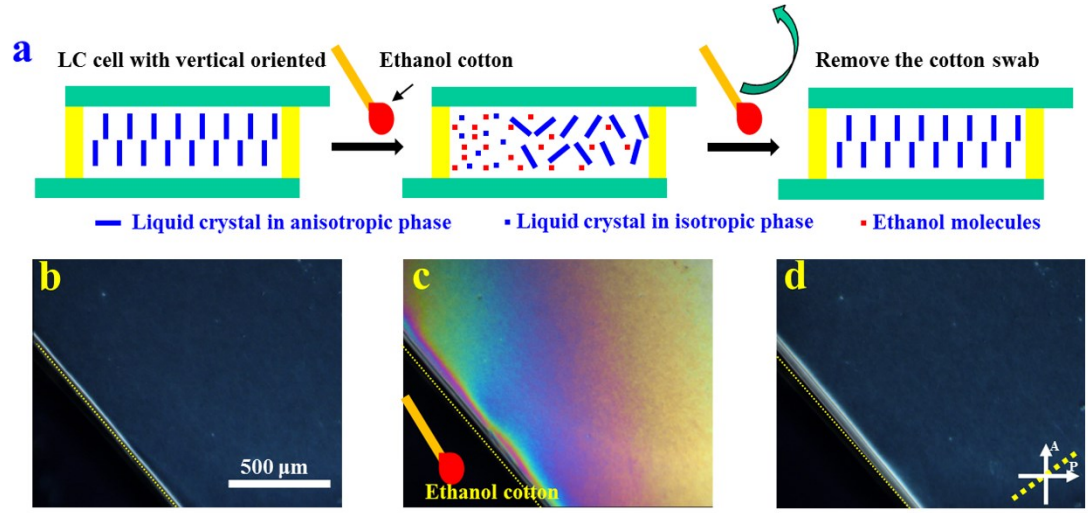

Fig. S2. (a) The detection process of the liquid crystal transition. The corresponding optical images of the LC cell with vertical oriented observed under POM. (b) Original state, (c) after adsorbing ethanol vapor, and (c) remove ethanol vapor.

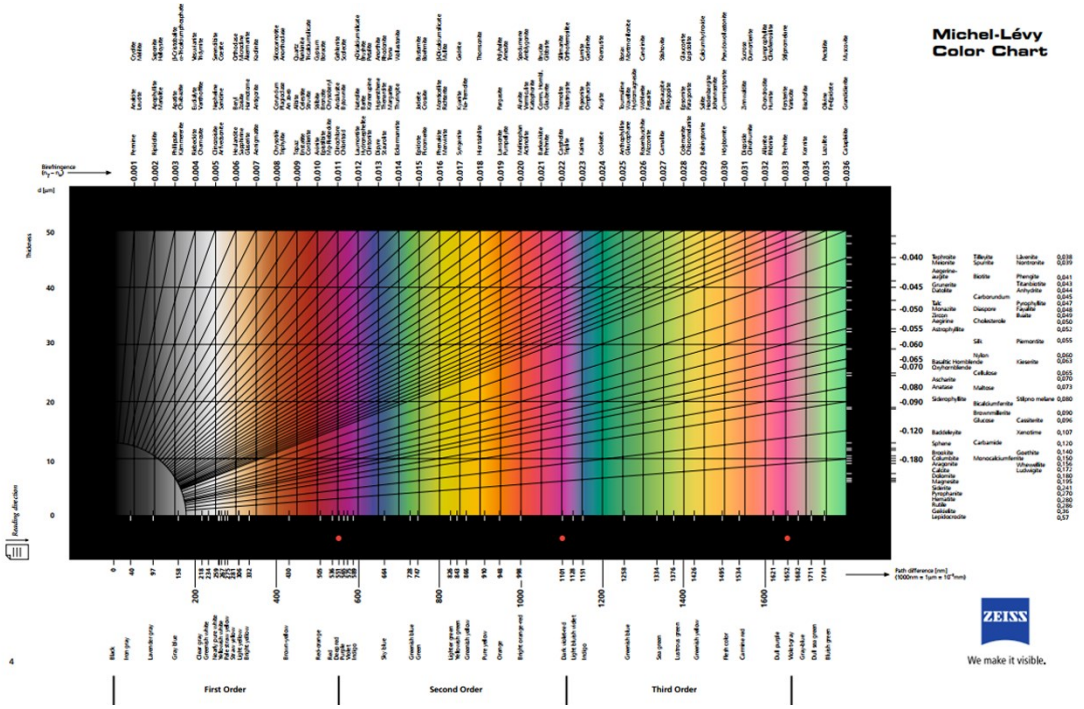

Fig. S3. Michel-levy color chart. (from Carl Zeiss Microscopy GmbH)

Figure S4: The transmission spectra of the MZI with LC-1001 measured with different temperature.

Figure S4 plots the transmission spectra of the fiber MZI blue-shifts with increasing temperature. The attenuation peak gets blue-shifts 1.335 nm to 1682.947 nm from attenuation peak wavelength of 1684.282 nm as the temperature increases from 25 °C to 40 °C. A small blue-shift phenomenon indicates that the interference spectrum of the LC-based MZI with LC-1001 can be achieved low crosstalk from temperature when the temperature changes between 25 °C and 40 °C, this result is consistent with the measurement of the LC-1001 refractive index. The attenuation peak wavelength blue-shifts from 1682.947 nm to 1666.7 nm, due to the large changes of the refractive index difference (n_e-n_o) of liquid crystal as the temperature increases from 40 °C to 55 °C. Therefore, the LC-based fiber MZI can realize low crosstalk from temperature when detection of VOC vapor at temperature range from 25 °C to 40 °C.

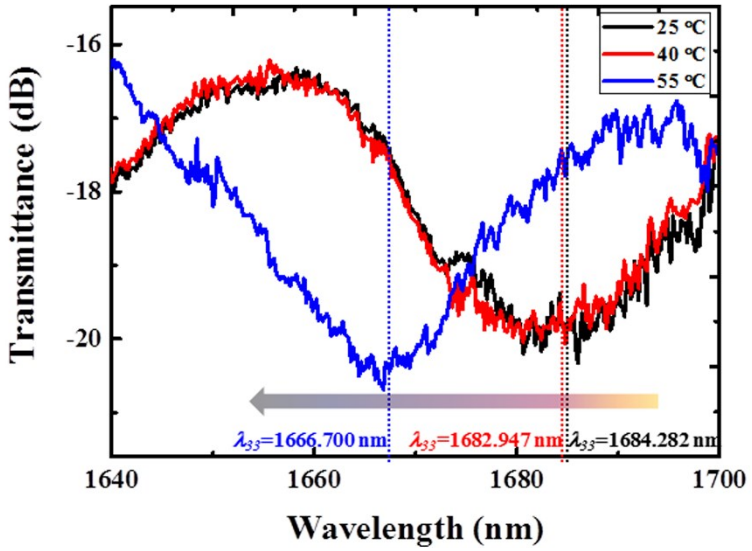

Fig. S4. The transmission spectra of the MZI with LC-1001 measured with temperature increases from 25 °C to 55 °C.