Electronic Supplementary Material (ESI) for Nanoscale.

Electronic Supporting Information

Direct writing of tunable multi-wavelength polymer lasers on a flexible substrate

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Degradation of polymer after UV radiations

The black and the green curves in Fig. S1 show the extinction spectra of F8BT before and after the interference ablation process, respectively. The blue and the red curves are the photoluminescence (PL) spectra of F8BT before and after the direct writing process, respectively. All curves are measured at the same site on the polymer film. The green/red curve is only slightly reduced in amplitude as compared with the black/blue curve, which may result from the reduced amount of the polymer at the ablation site. Thus, the transient exposure of the polymer film to a 5-ns UV laser pulse did not lead to the degradation of the remaining polymer.

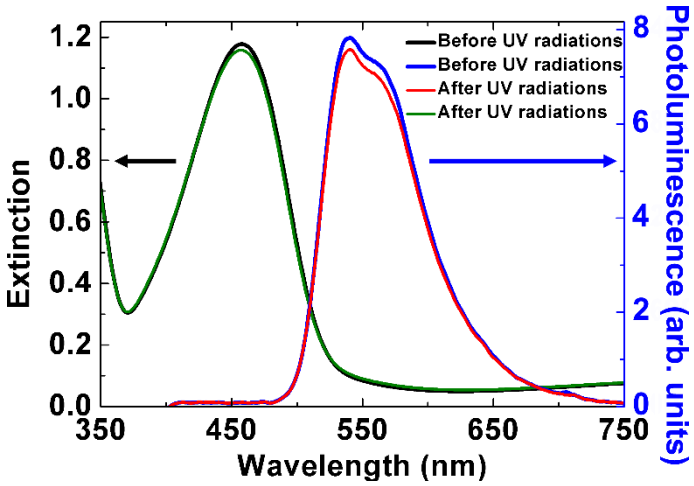

Figure S1. Extinction and photoluminescence spectra of F8BT before (black and blue curves) and after (green and red curves) the interference ablation.

It can be confirmed further by comparison with laser devices that have been fabricated using the conventional technique.

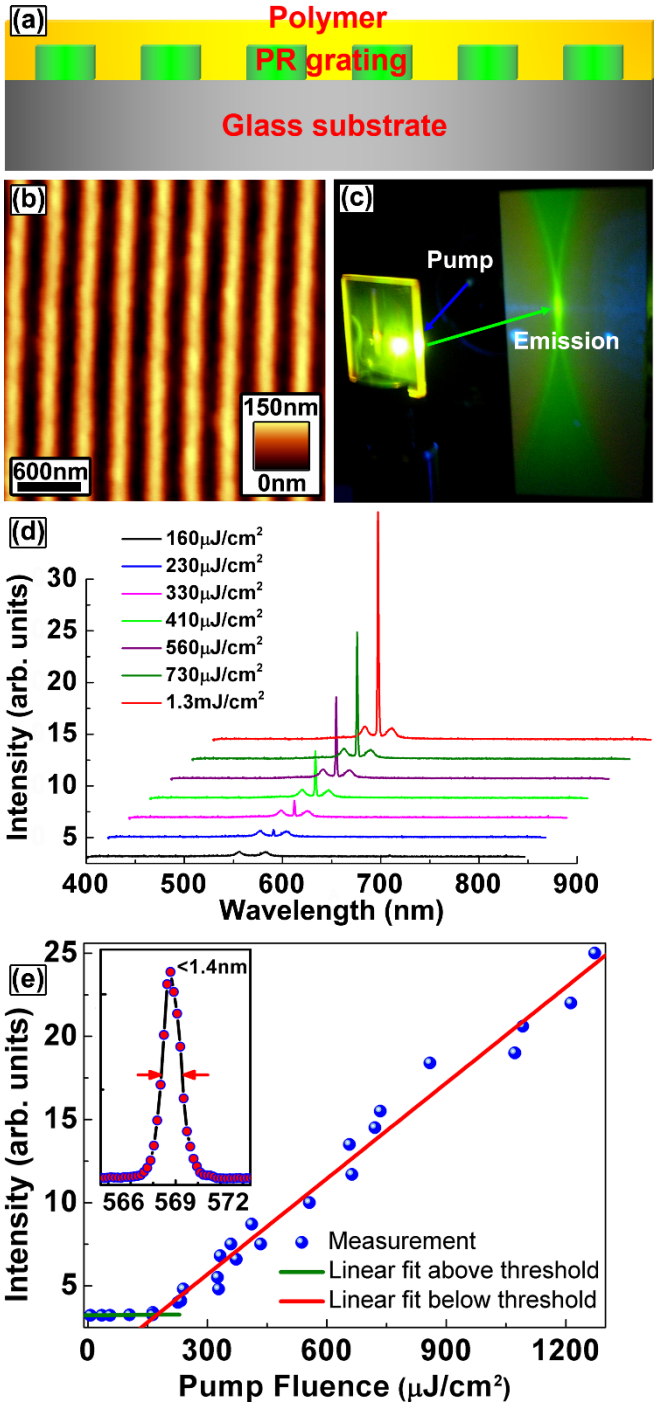

Figure S2. (a) The conventional design of the polymer laser with the active medium coated on top of the PR grating. (b) The AFM image of the grating. (c) The photograph of the operating polymer laser. (d) The spectra of the laser radiation at different pump fluence. (d) Output of the polymer laser as a function of the pump fluence, showing a pump threshold of about 170 μJ/cm^2. The linewidth of the laser output is less than 1.4 nm as shown in the inset.

Spin-coating of the polymer on top of a grating structure is a conventional technique for the fabrication of polymer lasers as shown in Fig. S2(a). As a control experiment,

a polymer lasers is fabricated by spin-coating the solution of F8BT in chloroform with a concentration of 20 mg/ml onto the photoresist (PR) grating, which is fabricated on a glass substrate by interference lithography. The PR grating has a period of 350 nm and a modulation depth of 150 nm as shown in Fig. S2(b). Figure S2(c) shows a photograph of the operating polymer laser. Figure S2(d) shows the emission spectra at different pump fluences. The emission intensity as a function of the pump fluence is demonstrated in Fig. S2(e), indicating a pump threshold of about 170 μJ/cm^2. Clearly, the polymer lasers fabricated by interference ablation have similar pump thresholds and narrower emission linewidths, which confirms that the 5-ns UV radiation during interference ablation did not lead to the degradation of the polymer film.

The independent tunability of the polymer lasers

Figure S3 demonstrates polymer lasers based single and double grating structures, respectively. The rectangular lattice structure consisting of two orthogonal gratings with different periods supports stable dual-wavelength laser output as shown in Fig. S3(c). Single-wavelength lasing emission can be realized in the one-dimensional polymer laser as shown in Fig. S3 (d).

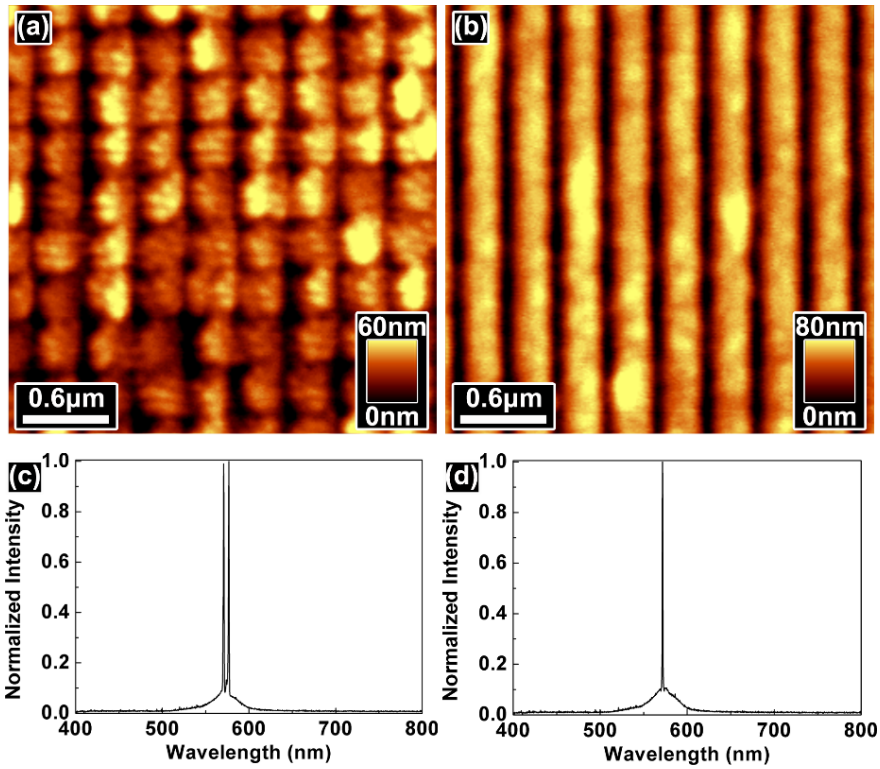

Figure S3. AFM images of polymer lasers based on (a) double-grating and (b) single-grating structures. The periods of two gratings in (a) are 355 nm and 360 nm, respectively. The period of the grating in (b) is 355 nm. Measured laser output spectra of (c) double-grating and (d) single-grating structures.

For the simple cavities in Fig. S3, the laser wavelength can be individually tuned by bending the soft substrate along the grating direction. However, it is impossible to tune each wavelength completely independently, because the three gratings were fabricated on the same soft substrate and they are overlapped at an intercrossing angle of about 60 degrees. In our experiment, one wavelength can keep unchanged while the other two wavelengths are tuned by bending the substrate along different orientations of the compound cavity as shown in Fig. S4.

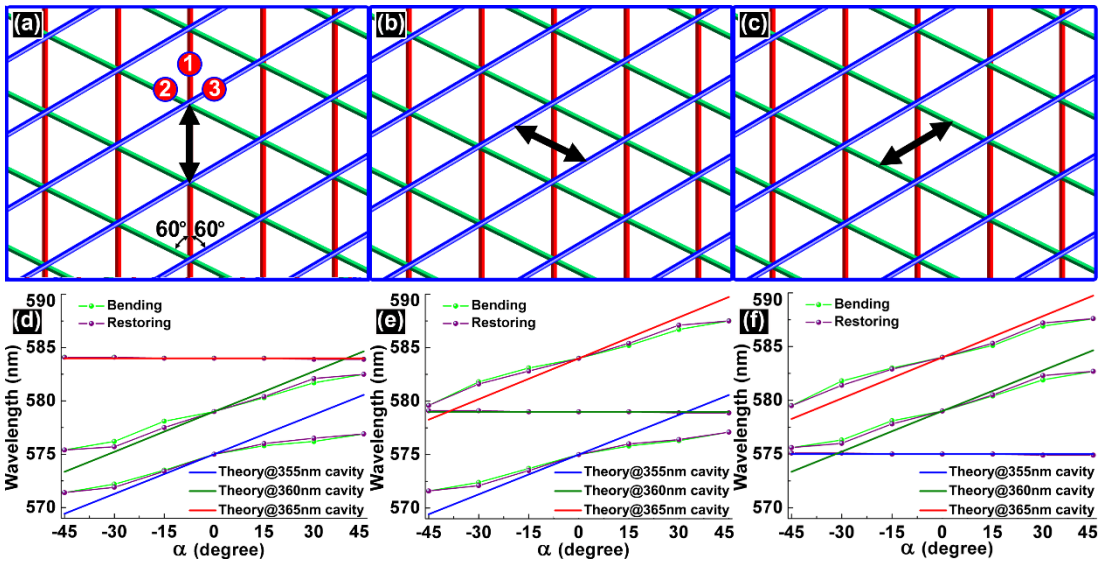

Figure S4. The spectroscopic response of the flexible laser device for bending and restoring processes, respectively. (a) A scalene triangular lattice consists of three gratings with different periods, indicating by ①, ②, and ③. The angle between two gratings is 60 degrees. The black arrows denote the bending direction along different orientations of (a) the 365 nm cavity, (b) the 360 nm cavity, and (c) the 355 nm cavity, respectively. The spectroscopic response of (a), (b), and (c) are demonstrated in (d), (e), and (f), respectively. The variation of the wavelength can be calculated by $\Lambda t\alpha/h_1$, where h_1=20 mm, and t=400 μm.

The polarization of the polymer lasers

The polarization of the pump beam has little influence on that of the laser output beam. A strongly polarized emission with high divergence parallel to the grating lines is observed as shown in Fig. S5, indicating that the tri-wavelength polymer laser can be considered as a linear combination of 1D DFB polymer lasers.

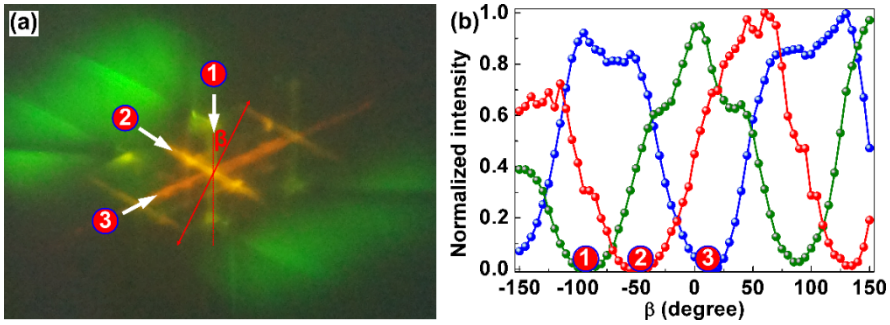

Figure S5. (a) Enlarged view of the laser spot. ①, ②, and ③ identify the emission wavelengths of the 355 nm, 360 nm, and 365 nm cavity, respectively. The red solid line denotes the polarization

direction of the polarizer. β is the angle between the polarization direction of the polarizer and the lasing line Φ. (b) The measured spectrum of the polarization direction of the output beam of the polymer laser.

The output of the polymer lasers

The direction of laser emission will change slightly due to the bending curvature of the substrate. During the wavelength-tuning measurements, in order to ensure the reliability of the experiment, the position of the detection head of spectrometer with respect to the sample was kept unchanged. Therefore, the bending of the substrate led to different intensity of the three lasing spectra. It is a normal case they are oscillation with different relative power. In the experiment, equal spectral intensities could be obtained by adjusting the detection positions and directions, as shown in Fig. S6. However, three peaks with different intensity contain a deeper physical meaning.

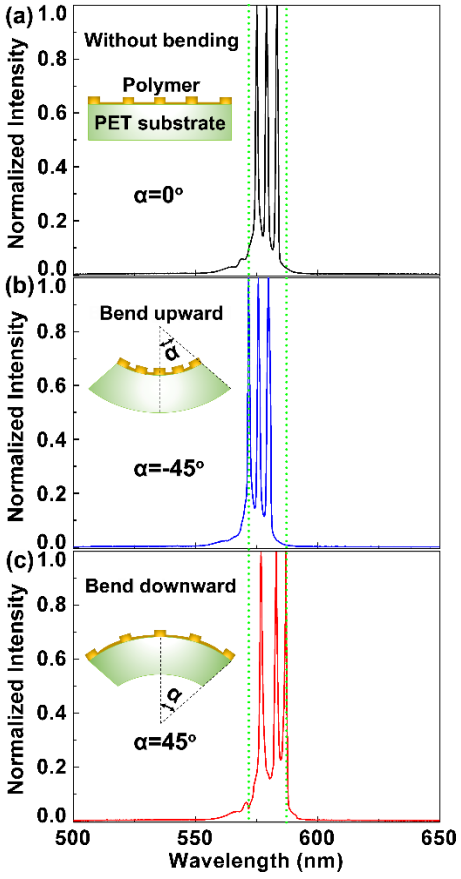

Figure S6. Measured spectra of the polymer laser (a) without bending, (b) with bending upward, and (c) with bending downward, where h_1=20 mm, h_2=18 mm and t=400 μm.