Experimental and Theoretical Investigation of Polymer Optical Fiber Random Laser in the Weakly Scattering Regime

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Abstract: A coherent polymer optical fiber random laser (doped with TiO_2 and fluorescent dye) in the weakly scattering regime is demonstrated. Moreover, we built a numerical model based on Monte Carlo method to describe experiment observation.
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1. Introduction

Random laser (RL) based on disordered system with optical gain medium has been a hot research topic in the past two decades due to their easy fabrication, unique properties, and promising applications.[1] The main difference between RL and conventional laser is the optical feedback mechanism. A conventional laser consists of two essential components: a gain medium and a cavity. The cavity, generally formed by two mirrors, provides coherent optical feedback for the stimulated emission in the gain medium. The light passes through the gain medium and gets amplified while bouncing back and forth between the mirrors. The optical feedback in a random laser is provided by multiple scattering of light in a disordered medium. Multiple scattering can increase the travel path length or time of light in the gain medium, hence the optical amplification by stimulated emission is enhanced.[2]

In present work, we demonstrated a polymer optical fiber RL (POFRL) with coherent feedback. The emission properties of POFRL were fully studied via performing both experiment and simulation.

2. Experiment

We fabricated a 5-cm long POFRL by doping TiO_2 and organic dye (Rh640 or R6G) in the core of the POF. The TiO_2 doping concentration was 400 ppm and the corresponding mean free path ls was calculated to be 600 nm. The emission properties of the POFRL were measured by a in-house setup, which consists of a Nd:YAG pulse laser (wavelength: 532 nm, pulse width: 6 ns), a HR4000 spectrometer, a power meter and several optical components. The output power of the laser can be varied by adjusting the Q-switch delay. The laser beam was focused into a thin stripe (length: 2.5 cm, width: 1 mm) to side-illuminate the POFRL, using the beam expander and the cylindrical lens. The emission spectra of the POFRL were collected by HR4000 spectrometer which has a wavelength measurement resolution of 0.2 nm.

Figure 1a shows the evolution of emission recorded for the POFRL excited at different pump powers. At low pump powers (sub-threshold), a broad spontaneous emission centered at 625 nm was observed and its full-width-half-maximum (FWHM) as measured to be approximately 35 nm. Several discrete narrow peaks (i. e. laser modes) started to emerge as the pump power exceeds the laser threshold, which indicate coherent random lasing was generated in the POFRL.1 The FWHM of the lasing mode narrowed down to 0.5 nm, which is two orders of magnitude smaller than the FWHM of the spontaneous emission peak. With increasing pump powers, the laser modes disappeared and only one sharp peak (center wavelength: 625 nm, FWHM: 12 nm) manifested in the spectrum.

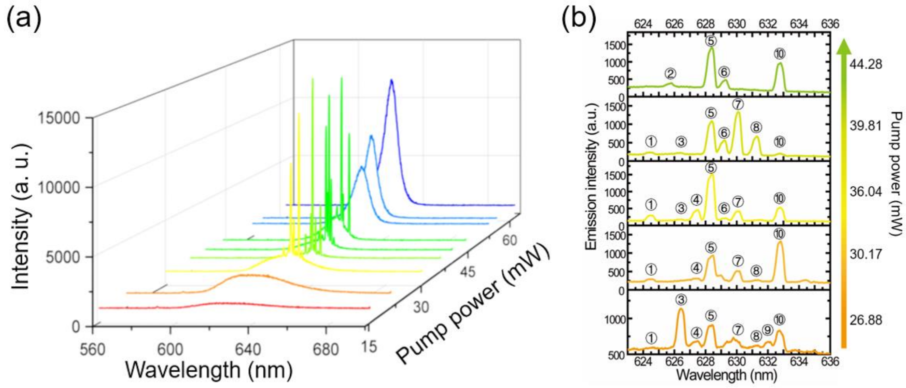

Figure 1. (a) Emission spectra of the POFRL at different pump powers. (b) Lasing spectra of the POFRL at pump powers above laser threshold. The corresponding pump powers are listed on the right side of the spectra. The laser modes are marked with numbers from 1 to 10.

Figure 1b shows several lasing spectra collected from the POFRL at different pump powers (above laser threshold). It can be seen that the wavelength of each laser mode was consistent. This is because the positions of the doped TiO_2 particles and the formed laser cavities were immobile. However, the intensities of these laser modes varied as the pump power changes. This can be attributed to the mode competition and the intrinsic statistical fluctuations of random laser.[3,4]

3. Simulation

In our experiment, ls (600 μm) is much larger than the light wavelength (around 600 nm), which means the interference effects don’t play a role in the POFRL system. To realize this lasing dynamic in our numerical models, a modified Monte Carlo method was employed.[5,6]

For simplicity, the simulation model is built based on a two-dimensional rectangle region with orthogonal grids (Figure 6). The orthogonal grids partitioned the simulation region into same size cells. Two sides of the rectangle region are set as reflective boundary representing the interface between the core and the cladding of the POF. The other two sides are set as output boundary, where the output photons are collected. The simulation model consists of an initialization step and a loop of three distinct steps, shown as following.

Step 0: Initialization. The scatterers are generated and occupy the cells. Their positions are randomly distributed among the simulation region. The totally number of the scatterers is determined by the mean free path lmfp. The unoccupied cells work as the active medium and they are homogeneously excited to have the initial population

Step 1: Spontaneous emission. Each cell (active medium) undergo a spontaneous emission process with a probability. When this event occurs, a new walker will be generated to carry one photon in a random propagation direction. Meanwhile, the population of this cell will be reduced by one unit.

Step 2: Diffusion. All the walkers located in the simulation region will move one unit along their propagation directions. When a walker encounters a reflective boundary or a scatterer, its propagation direction will be changed and its position is updated accordingly. When a walker reaches the output boundary, it will be “destroyed” (i.e. escaped from the simulation region) and its information (photons and frequency) will be collected.

Step 3: Stimulated emission. Each walker will interact with the cell in the same position. Part of the population of the cell will transfer to the walker and increase the walker’s photons.

Figure 2(a-c) shows the numerical spectra at three different pump powers. These pump powers were chosen to be subthreshold, near threshold, and well above threshold, respectively. When the pump powers are subthreshold and well above threshold, only a board emission peak can be observed in the spectra (Figure 2(a) and (c)). However, the numerical spectrum exhibits several discrete narrow peaks as the pump power is near threshold (Figure 2(b)). The numerical spectra are in good agreement with the experiment emission spectra of the POFRL.

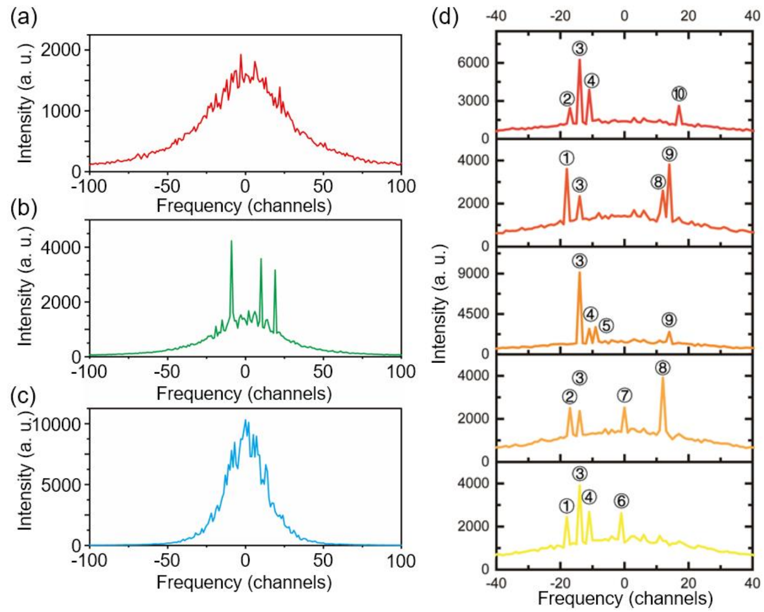

Figure 2. Numerical spectra at three pump powers (a) subthreshold, (b) near threshold, and (c) well above threshold, (d) Numerical spectra for 5 different shots at same pump power (near threshold). The laser modes are marked with numbers from 1 to 10.

Furthermore, we preformed the simulation 5 times at same pump power (near the laser threshold), as shown in Figure 2(d). Similar with the experiment observation, the peak wavelengths in the numerical spectra are immobile, whereas the intensities of the peaks changes from shot to shot. All the results indicate that the simulation model can well described the lasing dynamics of our POFRL.

4. References

[1] Luan F, Gu B, Gomes A S L, Yong K T, Wen S and Prasad P N, “Lasing in nanocomposite random media” Nano Today **10** 168–192 (2015)

[2] Cao H, “Lasing in random media Waves in Random Media” **13** R1–39 (2003)

[3] Merrill J W, Cao H and Dufresne E R, “Fluctuations and correlations of emission from random lasers” Phys. Rev. A **93** 1–5 (2016)

[4] Cao H, Jiang X, Ling Y, Xu J Y and Soukoulis C M, “Mode Repulsion and Mode Coupling in Random Lasers” Phys. Rev. B **13** (2003)

[5] Ignesti E, Tommasi F, Fini L, Lepri S, Radhalakshmi V, Wiersma D and Cavalieri S, “Experimental and theoretical investigation of statistical regimes in random laser emission” Phys. Rev. A **88** 33820 (2013)

[6] Lepri S, Cavalieri S, Oppo G-L and Wiersma D S, “Statistical regimes of random laser fluctuations” Phys. Rev. A **75** 63820 (2007)