The 26th Iranian Conference on Optics and Photonics (ICOP 2020), and the 12th Iranian Conference on Photonics Engineering and Technology (ICPET 2020).
Kharazmi University,
Tehran, Iran,
Feb. 4-5, 2020

لیزر تصادفی پلاسمونی دو کاناله بر پایه نانوساختار دو کاواکه شامل نانوسیم های نقره و پلیمرهای نور گسیل

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چکیده- لیزرهای تصادفی پلاسمونی به صورت چند طول موجی، از اهمیت بسزایی برخوردارند. از این رو در این مقاله به دنبال طراحی و ساخت چند لایه ای بر پایه پلیمرهای نورگسیل و نانوسیم های نقره هستیم. بر این اساس از جداکننده پلیمری PVP شامل نانوسیم های نقره به صورت کاواک در چند لایه ای استفاده نمودیم. نتایج نشان دهنده‌ی افزایش جابجایی آبی در لیزر به دلیل حضور نانوسیم های نقره و تاثیر آن در افزایش ضریب بهره است. همچنین به دلیل ماهیت کاواک گونه لایه شامل نانوسیم های نقره، طول موج برانگیخته دیگری نیز در طیف خروجی از نمونه مشاهده می شود که می تولندبازگشای پنجره ای جدید در لیزرهای تصادفی همدوی و غیر همدوس چند طول موجی باشد.

کلید واژه- لیزر تصادفی، نشدید پلاسمون سطحی، نانوسیم های نقره، سیستم چند لایه ای.

Efficient dual wavelength Random laser based on light emitting polymers and silver nanowires double cavity structure

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Abstract- double wavelength random lasing attained in multilayer structure based on silver nanowires. The main gain media contained poly-vinyl-pyrolydone matrix contains silver nanowires as two spacer layers in the multilayer structure. Our results show efficient blue shift in the lasing properties due to the overlap of surface plasmon resonance of nanowires in this region and also nonlinearity of silver nanowires. This result is very useful to design and construction of efficient multi wavelength coherent and in coherent random lasing.

Keywords: random laser, silver nanowires, multilayer, spacer, cavity.

1. Introduction

In recent years, the unique properties of the light-emitting polymers have received considerable attention as laser materials, due to the novel characteristics of temperature stability, broad spectrum, low cost and high quantum efficiency [1-3]. Based on these light emitting polymers, there is many kinds of tunable and multi-wavelength random lasers like as Green Blue Plasmonic Random Laser [4], red-green-blue (RGB) random Laser [5], tunable random lasers [6-7] and also random Fiber laser [8-9]. Moreover, the random lasers based on light-emitting polymers are focused for the properties of flexibility and lower lasing threshold. These type of polymers have opened wide prospects in the random laser [10], it's appropriate for the medical and sensing applications [11-12]. However, impossible to achieve multi-wavelength lasing oscillation in a single device. The directionality of the multi wavelengths random lasing emission can be improved by the waveguide effect of multilayer structure, so usually inserted very thick spacer layer between the active layers to prevent the strong coupling between different waveguides. For this reason, the spacer layer must be thinner thicknesses of the active layers.

In this work, a dual wavelength random laser consisting of three different layers of light-emitting polymer separated by two layers of poly-vinyl-pyrrolidone (PVP) spacers are fabricated by spin-coating method. The PVP layers are doped with silver nanowires (NWs) to provide plasmonic enhancement of the pump light.

2. Experimental part

We use three different active materials of light-emitting polymers the first layer: poly [2-methoxy-5-(3′, 7’-dimethyloctyloxy)-1,4 phenylenevinylene] (MDMOPPV, Sigma-Aldrich), the second layer poly[(9, 9-dioctylfluorenyl-2,7-diyl)-alt-co-(1,4-benzo-(2, 1’, 3)-thiadiazole)] (F8BT, American Dye Source) and the third poly[9, 9-dioctylfluorenyl-2, 7-diyl] end capped with DMP (PFO, American Dye Source), all these polymers dissolved in xylene with concentrations of 3, 8, 4 mg/mL, respectively. And water solution of spacer layer poly vinyl pyrrolidone (PVP) with a concentration of 3 mg/mL mixed with Ag NWs 1.2 mg/ml. Now coating all light-emitting polymers by spin-coated onto the glass substrate with a speed of 2000 rpm, the purpose of forming spacer layers coating the surface of the first active material (MDMO-PPV) and second active material (F8PT) with mixed (PVP and Ag NWs) solution by spin-coat at a speed of 3000 rounds per minutes (rpm). So, a five-layer structure is obtained to achieve a dual wavelength random lasing, as shown in Fig. 1. The spacer layers (PVA and Ag NWs) thickness is expected to be very thin to avoid exciting the waveguide modes.

We use the second harmonic generation of Nd: YAG laser to pump the sample from the side of the glass substrate with the repetition rate of 10 Hz and a pulse width of 5 ns and collect the lasing by Avantes spectrometer.

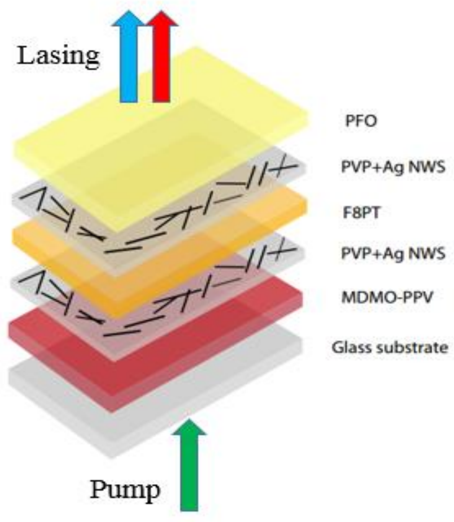

Fig 1. The green source pumping of the sample is incident from the side of the glass substrate.

3. Results and Discussion:

The optical absorption spectra of the multilayer structure measured by UV–Visible spectrophotometer is shown in Fig (2). Ag NWs scatter light more strongly than their dielectric counterpart within the spectral range of the surface plasmon resonance (SPR) of it. Note that the absorbance spectrum of the multilayer structure with Ag NWs has two peaks are observed at 325 and 465 nm.

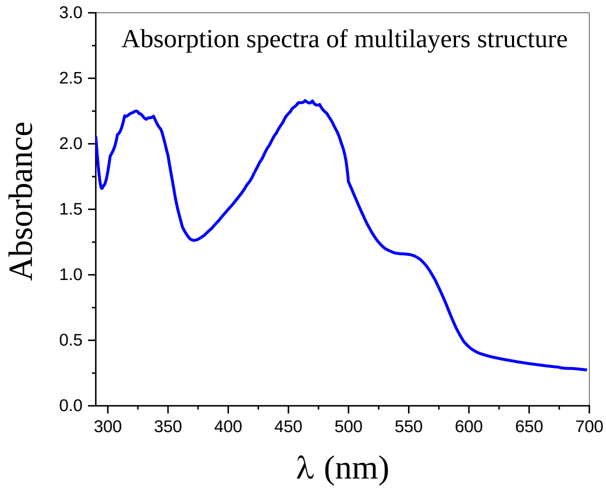

Figure 2. Absorption spectrum of the multilayer structure.

As shown in this figure, the plasmonic resonance peak of Ag NWs overlaps with the pump source to enhance the gain of lasing. So, the Ag NWs mainly provide enhanced pumping for random lasing.

Fig. 3 shows the measured emission spectrum of a dual-wavelength random laser on five layers structure. Two random lasing peaks are present in the emission spectra the blue wavelength range from 450 to 470 nm and decrease the width and enhance the number of spikes with increased energy pumping, and the red wavelength at 600nm and this implies that the layer spacers inhibit optical coupling between the different waveguides.

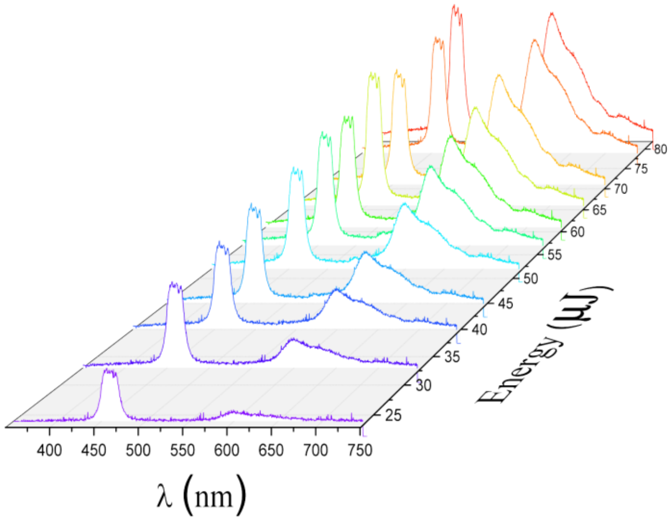

Figure 3: Measured emission spectra of the multi wavelength random lasing.

In addition, we observe that with increase in the pump energy, the emission intensity increasing with a lot of number of spikes appear in this range, due to the SPRs of Ag NWs.

4. Conclusion:

Low-threshold and dual wavelength random lasing is observed simultaneously with the pump energy above the threshold of the multi-layer structure as laser device. This lasing enhances at blue spectral region because of the influence of SPR of silver NWs into the PVP layers. Also due to repetition of this layer twice times in the structure, we have second lasing region in the multilayer.

References

[1] Bulovi, V. "Transform-Limited, Narrow-Linewidth Lasing Action in Organic Semiconductor Microcavities." *Science* 279, no. 5350 (1998), 553-555. doi:10.1126/science.279.5350.553.

[2] Cerdán, Luis, Angel Costela, and Inmaculada García-Moreno. "Waveguided random lasing in red-emitting-dye-doped organic–inorganic hybrid polymer thin films." *Organic Electronics* 13, no. 8

(2012), 1463-1469. doi:10.1016/j.orgel.2012.04.017.

[3] Heydari, Esmaeil, Isabel Pastoriza-Santos, Luis M. Liz-Marzán, and Joachim Stumpe. "Nanoplasmonically-engineered random lasing in organic semiconductor thin films." *Nanoscale Horizons* 2, no. 5 (2017), 261-266. doi:10.1039/c7nh00054e.

[4] S.F. Haddawi, M. Mirahmadi, H. Mbarak, A.K. Kodeary, M. Ghasemi, S. M. Hamidi, "Footprint of Plexitonic States in Low Power Green Blue Plasmonic Random Laser", Journal of Applied Physics A (2019).

[5] Shi, Xiaoyu, Yanrong Wang, Zhaona Wang, Sujun Wei, Yanyan Sun, Dahe Liu, Jing Zhou, Yongyi Zhang, and Jinwei Shi. "Random Lasing with a High Quality Factor over the Whole Visible Range Based on Cascade Energy Transfer." *Advanced Optical Materials* 2, no. 1 (2013), 88-93. doi:10.1002/adom.201300299.

[6] El-Dardiry, Ramy G., and Ad Lagendijk. "Tuning random lasers by engineered absorption." *Applied Physics Letters* 98, no. 16 (2011), 161106. doi:10.1063/1.3571452.

[7] Wiersma, Diederik S., and Stefano Cavalieri. "A temperature-tunable random laser." *Nature* 414, no. 6865 (2001), 708-709. doi:10.1038/414708a.

[8] Babin, S. A., A. E. El-Taher, P. Harper, E. V. Podivilov, and S. K. Turitsyn. "Tunable random fiber laser." *Physical Review A* 84, no. 2 (2011). doi:10.1103/physreva.84.021805.

[9] Turitsyn, Sergei K., Sergey A. Babin, Dmitry V. Churkin, Ilya D. Vatnik, Maxim Nikulin, and Evgenii V. Podivilov. "Random distributed feedback fibre lasers." *Physics Reports* 542, no. 2 (2014), 133-193. doi:10.1016/j.physrep.2014.02.011.

[10] Samuel, I. D., and G. A. Turnbull. "Organic Semiconductor Lasers." *Chemical Reviews* 107, no. 4 (2007), 1272-1295. doi:10.1021/cr050152i.

[11] Hill, Martin T., and Malte C. Gather. "Advances in small lasers." *Nature Photonics* 8, no. 12 (2014), 908-918. doi:10.1038/nphoton.2014.239.

[12] Polson, Randal C., and Z. V. Vardeny. "Random lasing in human tissues." *Applied Physics Letters* 85, no. 7 (2004), 1289-1291. doi:10.1063/1.1782259.