Kütahya Dumlupınar University
Institute of Graduate Studies

Journal of Scientific
Reports-A
E-ISSN: 2687-6167
Number 51, December 2022

RESEARCH ARTICLE

WAVELENGTH TUNABLE PASSIVELY Q-SWITCHED FIBER RING LASER USING GALLIUM ARSENIDE BASED MICROCHIP SATURABLE ABSORBER

Thoalfeqar Ali Razaq ALYASIRI[1], Aşkınnur AŞKIN[2], Bünyamin KAYA[3], Şerif Ali SADIK[4*,] Fırat Ertaç DURAK[5], Ahmet ALTUNCU[6]

[1]Kütahya Dumlupınar University, Photonics Technologies Application and Research Center (FOTAM), Kütahya, thoalfeqar.alyasiri@ogr.dpu.edu.tr ,ORCID: 0000-0002-8379-0751
[2]Kütahya Dumlupınar University, Photonics Technologies Application and Research Center (FOTAM), Kütahya, askinnur.askin@org.dpu.edu.tr, ORCID: 0000-0003-0953-0246
[3]Kütahya Dumlupınar University, Photonics Technologies Application and Research Center (FOTAM), Kütahya, bunyamin.kaya2@ogr.dpu.edu.tr, ORCID: 0000-0002-9907-2826
[4]Kütahya Dumlupınar University, Photonics Technologies Application and Research Center (FOTAM), Kütahya, serifali.sadik@dpu.edu.tr, ORCID: 0000-0003-2883-1431
[5]Kütahya Dumlupınar University, Photonics Technologies Application and Research Center (FOTAM), Kütahya, firat.durak@dpu.edu.tr, ORCID: 0000-0002-4278-6561
[6]Kütahya Dumlupınar University, Photonics Technologies Application and Research Center (FOTAM), Kütahya, altuncu@dpu.edu.tr, ORCID: 0000-0002-3753-9515

Receive Date:31.08.2022 *Accepted Date: 05.10.2022*

ABSTRACT

The work presented in this study is focused on developing a widely wavelength tunable Q-switched pulsed erbium doped fiber ring laser (EDFRL) source operating in microsecond regime in Telecom wavelength spectrum of 1.55 µm (C and L bands). A commercial Gallium arsenide (GaAs) based microchip saturable absorber (SA) is used in the proposed EDFRL configuration to passively initiate Q-switching for stable pulse generation. Unless low damage threshold of the commercial GaAs based SA and non-optimized cavity length and losses, sufficiently stable pulse trains were obtained for a wide wavelength tuning range of 50 nm from 1520 nm to 1570 nm with high repeatability and long-term stability. The Q-switched output pulses of the proposed EDFRL have output average powers varying from +0.65 dBm to +1.53 dBm, the pulse widths varying from 4.27 µs to 7.16 µs and the repetition rates varying from 51.51 kHz to 31.42 kHz for different tuning wavelengths.

Keywords: *fiber laser, saturable absorber, Q-switched, wavelength tunable*

1. INTRODUCTION

Q-switched fiber lasers can generate high-energy pulses by modulating optical losses in the laser cavity using active or passive modulation elements. Therefore, studies on Q-switched fiber lasers have increased recently. Many modulators such as electro-optic modulators (EOM) [1], acousto-optic modulators (AOM) [2], semiconductor saturable absorber mirrors (SESAMs) [3], microchip saturable absorbers [4], and film saturable absorbers [5], carbon nanotubes [6], topological insulators (TIs) [7], graphene [8], transition metal dichalcogenides (TMDs) [9] have been utilized to achieve Q-switching pulses. In contrast with the mode-locked ones, Q-switched fiber lasers have the ability to generate much higher pulse energy with microsecond or nanosecond pulses. Also, it is necessary to balance the dispersion and control the non-linear effects in the mode-locking process, which requires precise calculations and are not needed in the Q-switching process. Therefore, Q-switched fiber lasers have the advantages of efficiency, low cost, and ease of construction. The Q-switched lasers have many potential applications in various fields, such as sensing applications [10, 11], medicine [12] and material processing [13] owing to their advantages such as fast recovery time and low saturation intensity.

Passively Q-switched microchip lasers have many advantages, simplicity of implementation, pulse generation with a well-defined energy and duration, highly stable operation and easier to obtain single-frequency operation in a passively Q-switched laser than in an actively Q-switched device. The pulse duration from a Q-switched laser generally decreases with decreasing cavity length [14] and its central lasing wavelength can be passively tuned over a wide spectrum in C and L bands as soon as providing a positive gain spectrum using a wideband erbium doped fiber amplifier inside the cavity.

In this work, we demonstrate a widely tunable Q-switched erbium doped fiber ring laser with a gallium arsenide (GaAs) based saturable absorber (SA) as a passive Q-switching element, and an optical tunable band pass filter (OTBPF) as a wavelength tuning element. Stable Q-switched pulses are obtained in a 50 nm wide wavelength tuning range, which can be tuned from 1520 nm to 1570 nm. The obtained pulses have pulse widths ranging from 4.27 μs to 7.16 μs and repetition rates from 51.51 to 31.42 kHz.

2. EXPERIMENTAL DESIGN

In the experimental design utilized in this work, one backward pump laser diode and one forward pump laser diode with operating wavelengths of 980 nm were used to provide high pump power (Optical output power of the both of the laser diodes were set to 150 mW). An active fiber (Liekki Er-30) with the length of 6 m was utilized in the experimental setup. The length of the erbium doped fiber (EDF) was chosen to obtain a wideband CW operation in EDFRL using our previous results [15]. An isolator was utilized inside the ring cavity to ensure unidirectional lasing operation. To select the lasing wavelength of EDFRL, a MEMS-based C+L band OTBPF (TF1C100) was used in the cavity. A commercial GaAs microchip based SA is used as saturable absorber medium for pulse generation. The commercial SA used was 150 μm in thickness and had an absorbance of 58%, modulation depth of 35% and saturation fluence of 300μJ/cm2 at 1550 nm. The output of EDFRL was taken from the 10% port of the tap coupler with a 90% - 10% splitting ratio and then split into two ports, to observe the optical spectrum of the output signal and the electrical pulse forms simultaneously. The optical signal was analyzed at the optical spectrum analyzer (OSA Anritsu MS9710B). At the other port of the coupler, the optical signal was detected via an InGaAs 5 GHz photodiode (Thorlabs-DET08CFC/M), and the pulse waveforms were analyzed with an oscilloscope (Keysight-DSOX2002A). In the experimental setup, a manual polarization controller (PC) was used to optimize the polarization state of the light in the ring cavity, to eliminate the unwanted polarization effects. The schematic representation of the experimental setup was given in Fig.1.

JSR A
Journal of Scientific Reports

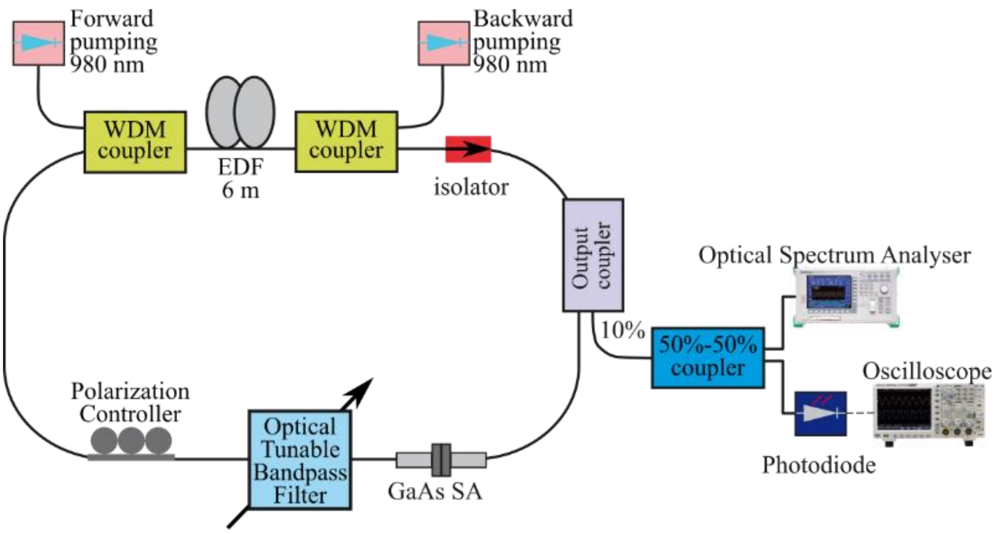

Figure 1. The proposed Q-switched EDFRL cavity used in experiments.

3. EXPERIMENTAL RESULTS

In the first experiment, the gain spectrum of the EDFA used in the setup was characterized using a commercial widely tunable (1520 nm-1607 nm) laser source (TLS) as the input light source. In these measurements, the forward and backward pump laser powers were set to 140 mW and the center wavelength of the TLS was tuned in the range of 1520-1607 nm. The gain spectrum of the bidirectional pumped EDFA is shown in Fig.2, which shows sufficient positive gains for a Q switched operation in our EDFRL design.

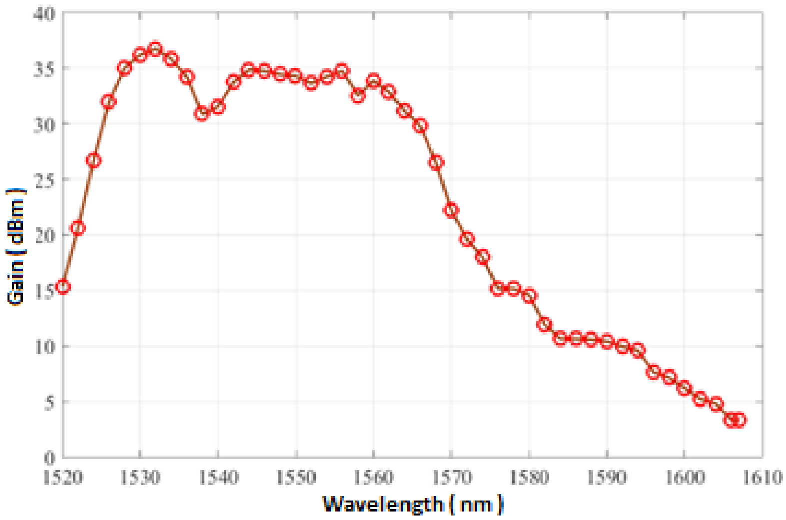

Figure 2. Gain spectrum of EDFA designed with 6 m EDF.

In the second experiment, passively Q switched EDFRL configuration has been set up as seen in Fig.1 using a GaAs based microchip saturable absorber. In Table 1, the optical output power, repetition rate and pulse width values obtained at the output of the Q switched wavelength tunable fiber ring laser designed across the entire spectrum are given. It should be noted that the output average power values measured in OSA were taken from one of the output ports of the 50%-50% splitter added to the assembly at the EDFRL output. It means that the power values given in Table 1 correspond to half the actual output power of the designed Q switched wavelength tunable EDFRL.

Table 1. The repetition rate, pulse width and output power of Q-switched wavelength tunable fiber ring laser.

Wavelength (nm)	Repetition Rate (kHz)	Pulse width (µs)	Output Peak Power (dBm)
1520	47.010	4.35	- 2.65
1530	51.516	4.274	- 2.63
1535	45.446	4.676	- 2.33
1540	38.459	4.982	- 1.74
1545	38.026	5.11	- 1.97
1550	39.435	5.334	- 1.58
1555	36.813	5.234	- 1.58
1560	33.928	5.554	- 1.54
1565	33.562	6.494	-2.03
1570	31.421	7.166	-1.53

JSR A
Journal of Scientific Reports

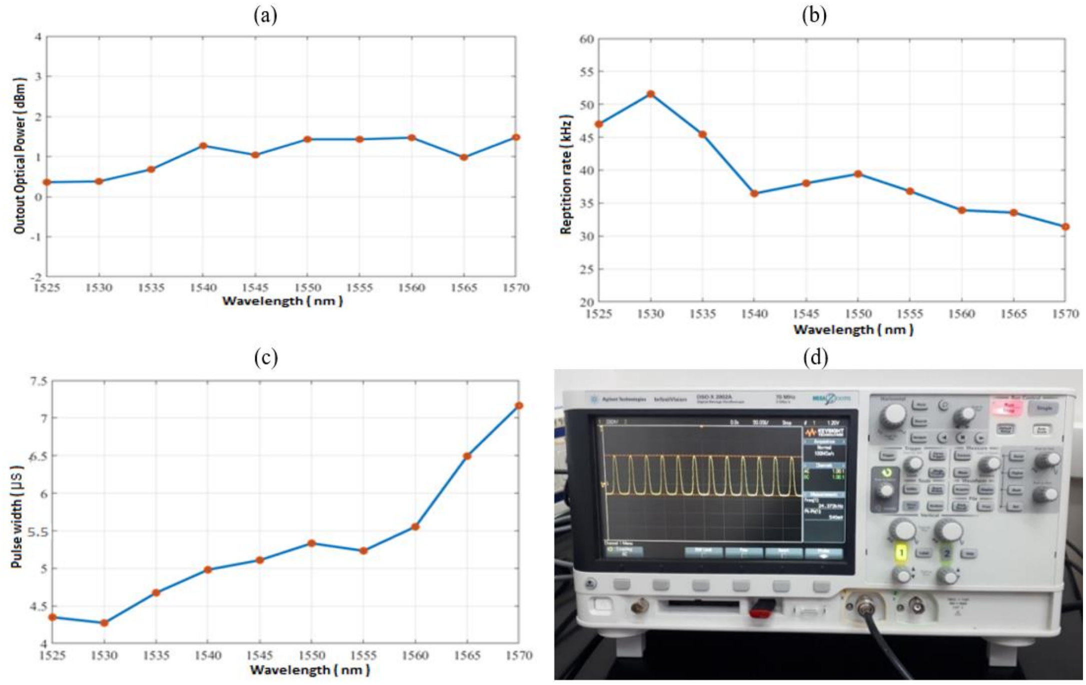

Figure 3. (a) Optical output power **(b)** Repetition rate and **(c)** Pulse width of the Q switched EDFRL as a function of tuning wavelength **(d)** A typical output waveform of the designed GaAs-SA based Q-switched wavelength tunable fiber laser.

With the Q-switched pulsed EDFRL design, highly stable pulses could be obtained for the lasing wavelength range of 1520-1570 nm having clearly measurable repetition rate, pulse width and output power values. The Optical output power, repetition rate and pulse width values measured through a 50 nm tunable wavelength range are given in Figure 3 (a), (b) and (c). The output average power measured in OSA at one port of the output splitter was changing between 0.65 dBm to 1.5 dBm depending on the lasing wavelength which correspond to the repetition rates varying between 31.42 kHz and 51.51 kHz and pulse widths varying between 4.35 µs and 7.16 µs.

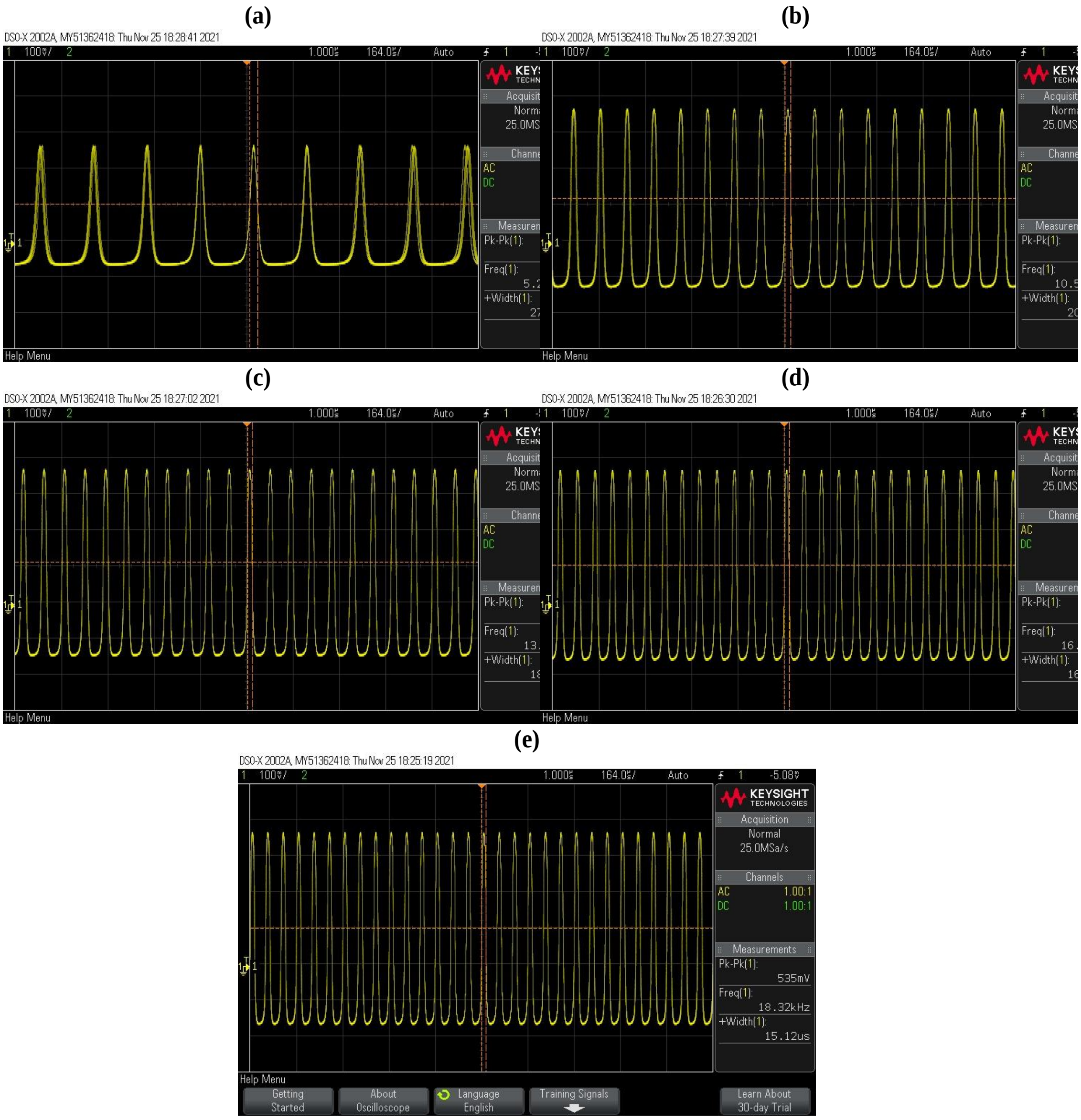

Figure 4. The Q-switched EDFRL output pulse trains at the lasing wavelength of 1567 nm obtained without using a OTBPF in the cavity at the following pump currents of **(a)** 60 mA, **(b)** 70 mA, **(c)** 80 mA, **(d)** 90 mA, **(e)** 100 mA.

A self-starting and stable Q-switched fiber laser operation using GaAs SA without OTBPF was achieved after the threshold pump currents of 60 mA. The lasing oscillation was centered at a wavelength of 1567 nm. The Q-switched lasing operation remained stable as the pump laser currents were raised up to 100 mA. Fig.4 shows the increment of the repetition rate from 5.27 kHz to 18.32 kHz and the decreasement of the pulse with from 27.64 µs to 15.12 µs as the pump laser currents were increased from 60 mA to 100 mA.

4. CONCLUSION

In this study, highly stable Q-switched output pulses have been obtained in a bidirectionally pumped EDFRL configuration for a tunable wavelength range of 50 nm from 1520 nm to 1570 nm with an output average power of between +0.65 dBm and +1.53 dBm, the pulse width of 4.27 µs – 7.16 µs and the repetition rate of 51.51 kHz - 31.42 kHz for a moderate pumping level and non-optimized cavity losses. The Q switched output pulse trains were also obtained for different pumping levels at a natural lasing wavelength of 1567 nm in the cavity. The results show that Q-switching performance of wavelength tunable EDFRL design proposed can further be upgraded by optimizing the cavity length and losses. However, low damage threshold of GaAs based SA is serious limiting factor to be considered for high power applications. This kind of EDFRL Q switched pulse source can be widely used as a tunable laser source in DWDM optical communication systems operating in 1.55 µm region and for spectral response measurements in fiber optical sensor applications. In our future work, we will work on optimizing the cavity length and loss for a better Q-switching performance regarding wavelength tuning range, pulse width, repetition rate and output power.

ACKNOWLEDGEMENTS

This work was supported by Kütahya Dumlupınar University (Project No.DPU.2020-20).

REFERENCES

[1] El-Sherif, A.F. and King, T.A., (2003), High-energy, high-brightness Q-switched Tm^{3+}-doped fiber laser using an electro-optic modulator, Opt. Commun., 218(4),337-344.

[2] Li, W., Liu, H., Zhang, J., Long, H., Feng. S. and Mao, Q., (2016), Q-switched fiber laser based on an acousto-optic modulator with injection seeding technique, Appl. Opt., 55(17), 4584-4588.

[3] Wang, M., Chen, C., Huang, C., and Chen, H., (2014), Passively Q-switched Er-doped fiber laser using a semiconductor saturable absorber mirror, Optik (Stuttg)., 125(9), 2154–2156.

[4] J. J. Zayhowski, J.J., and Wilson, A.L., (2003), Pump-induced bleaching of the saturable absorber in short-pulse Nd:YAG/Cr/sup 4+/:YAG passively Q-switched microchip lasers, IEEE J. Quantum Electron., 39(12), 1588–1593.

[5] Zulkipli, N.F., Rosol, A.H.A., Sadik, S.A., Durak, F.E., Altuncu, A., Yasin, M. and Harun, S.W., (2021), Q-Switched Pulse Generation in a Bidirectionally Pumped EDFL Utilizing Lu_2O_3 as Saturable Absorber, Optoelectronics Letters, 17 (9), 529–533.

[6] Kasim, N., Al-Masoodi, A.H.H., Ahmad, F., Munajat, Y., Ahmad, H., and Harun, S.W., (2014), Q-switched ytterbium doped fiber laser using multi-walled carbon nanotubes saturable absorber, Chinese Opt. Lett.,12(3), 31403.

[7] Yu, Z., Song, Y., Tian, J., Dou, Z., Guoyu, H., Li, K., Li, H., and Zhang, X., (2014), High-Repetition-Rate Q-Switched Fiber Laser with High Quality Topological Insulator Bi_2Se_3 Film, Optics Express, 22(10), 11508–11515.

[8] Luo, Z.,Zhou, Z., Weng, J., Huang, G., Xu, H., Ye, C., and Cai, Z., (2010), Graphene-Based Passively Q-Switched Dual-Wavelength Erbium-Doped Fiber Laser. Optics Letters,35(21), 3709–3711.

[9] Chen, B., Zhang, X., Wu, K., Wang, H., Wang, J., and Chen, J., (2015), Q-switched fiber laser based on transition metal dichalcogenides MoS_2, $MoSe_2$, WS_2, and WSe_2, Opt. Express, 23(20), 26723–26737.

[10] Zhang, Q., Chang, J., Wang, Q., Wang, Z., Wang, F., and Qin, Z., (2018), Acousto-optic Q-switched fiber laser-based intra-cavity photoacoustic spectroscopy for trace gas detection, Sensors, 18(1), 42.

[11] Shi, W., Petersen, E., Moor, N., Chavez-Pirson, A., and Peyghambarian, N., (2011), All fiber-based single-frequency Q-switched laser pulses at 2 um for lidar and remote sensing applications, in Proc.SPIE, 2011, vol. 8164.

[12] Celen, S. , Özden, H. and Uyar, E. (2014), İterbiyum-katkili fiber lazerle Q-anahtarlamalı modda implant yüzeyi mikro-imalatı ve karekterizasyonu . Gazi University Journal of Science Part C: Design and Technology , 2 (2) , 197-202 .

[13] Ismail, M.A., Ahmad, F., Harun, S.W., Arof, H., and Ahmad, H., (2013), A Q-switched erbium-doped fiber laser with a graphene saturable absorber, Laser Phys. Lett.,10(2), 25102.

[14] Chen, Y., Zhao, C., Chen, S., Du, J., Tang, P., Jiang, G., Zhang, H., Wen, S., and Tang, D., (2013), Large Energy, Wavelength Widely Tunable, Topological Insulator Q-Switched Erbium-Doped Fiber Laser, IEEE Journal of Selected Topics in Quantum Electronics,20(5),315–322.

[15] Sadik, S. A., Durak, F. E., & Altuncu, A. (2020), Widely tunable erbium doped fiber ring laser based on loop and double-pass EDFA design. Optics & Laser Technology, 124, 105979.