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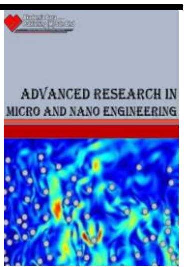

Q-Switched Pulse Generation in Erbium-based with Niobium Aluminium Carbide Saturable Absorber

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ABSTRACT

The viability of using Niobium Aluminum Carbide (Nb_2AlC) as a saturable absorber (SA) for Q-switched pulse production utilized in erbium arrangement is reported in this research. Polyvinyl alcohol (PVA) and the MAX phase material Nb_2AlC were successfully mixed to create a SA film, which was then placed between two fiber ferrules and inserted into the cavity. Steady Q-switched pulses at 1531 nm with a maximum repetition rate of 58.21 kHz and a minimum pulse width of 3.82 s were seen after raising the pumping power from 45.45 to 81.97 mW. The highest pulse energy was measured to be 42.26 nJ at a pump power of 81.97 mW. These findings show that Nb_2AlC MAX-phase material can be used to make SAs that are both useful and affordable.

1. Introduction

Due to the demand for such lasers in a variety of industrial applications, including laser removal, toenail fungus treatment, non-ablative skin resurfacing, and pigmented lesion therapy, Q-switched-based optic fiber is of significant interest [1]. These lasers can be generated utilizing either active or inactive techniques. To actively start laser pulses, modulators such as acousto and electro-optics are

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generally used. These active approaches involve an electrical signal that modifies intracavity loss and starts pulse production [2]. Frequently, additional components such as mirrors are required for mechanical switches, making the installation of an active approach cumbersome. It also has a signal distortion between components and necessitates regular arrangements. Passive strategies entail modifying a saturable absorber's saturable absorption property (SA). This approach is chosen because it eliminates the need for alignment and results in a smaller cavity loss, which raises the quality of the output pulse [3].

Because of its low cost and simple construction, the application of a SA in a fiberized cavity has been extensively studied. SAs based on a variety of nanomaterials have been used in a number of experiments on pulse laser generation. Graphene has some qualities, such as a wide operating spectrum span and a quick recovery time [4,5], but it also has some major drawbacks, including slow modulation depth and zero bandgaps [6]. Sb_2Te_3, Bi_2Te_3, and Bi_2Se_3 are examples of topological insulators that have been used to create laser pulses that operate over a range of wavelengths [7-9].

However, topological insulators have structural instability and chemical reactivity [10]. The peculiar absorption characteristics of transition metal dichalcogenides were demonstrated by tungsten disulfide (WS_2) [11], molybdenum disulfide (MoS_2) [12], molybdenum tetrafluoride ($MoTe_2$) [13], and tungsten disulfide (WSe_2) [14]. They are, however, limited by their difficult fabrication procedures and low optical damage threshold [15]. Due to its readily fabricated nature and broadband nonlinear optical response, black phosphorous was used in numerous fiber laser pulse applications [16]. However, this material quickly deteriorates when exposed to oxygen or water [17].

MAX phases are layered hexagonal carbides or nitrides shaped from the Mn+1AXn (n= 1–3) compounds. The M is a transition metal, A is a 13–16 group element and X is stand for carbon or nitrogen. The combination of metallic and ceramic properties results in the MAX phases, which exhibit unique properties [18]. Minimal density, low coefficient in thermal growth, and excellent resistance of oxidation are some of the properties of MAX phases. Their high damage tolerance and good machinability make them comparable to metals when it comes to electrical and thermal conductivity and machinability [19]. Therefore, we present the results of the q-switching experimental analysis of the MAX-phase Nb_2AlC based on erbium arrangement.

2. Methodology

MAX-PVA was created by fusing polyvinyl alcohol (PVA) (Sigma-Aldrich, Malaysia) with Nb_2AlC (Sigma-Aldrich, Malaysia). PVA has been shown to be a reliable host polymer for thin film preparation due to its excellent film-forming ability, high tensile strength, ease of emulsification, and high solubility in water. According to Figure 1, an all-fiber structure was used to build the EDFL ring cavity, with the Nb_2AlC-PVA based SA serving as its primary component. The material of the active laser was an erbium-doped fiber (EDF) with a length of 2.4 m. At the pumping wavelength of 980 nm, it has a numerical aperture (NA) of 0.23 and a core/cladding diameter of 4 mm/125 mm. A 980/1550 nm wavelength-division multiplexer connected the EDF to the 980 nm diode laser pump source (WDM). An isolator is attached to the opposite end of the EDF to maintain the unidirectional propagation of the oscillating laser in the ring laser cavity.

The Q-factor of the cavity was altered by the SA film, which automatically adjusted the intra-cavity loss. The loop was then completed by light traveling via an 80:20 optical coupler, which splits the laser's total production into 20% for spectral analysis and 80% for the cavity. The profile and quality of the Q-switching signal were observed using a photodetector, a radio frequency spectrum analyzer (RFSA, Anritsu, MS2683A, Tokyo, Japan), a digital oscilloscope (GWINSEK, GDS-3502, 500MHz Bandwidth, Seoul, Korea), and an optical spectrum analyzer (OSA, Anritsu, MS9710C, Tokyo, Japan) to determine the intended output of optical qualities.

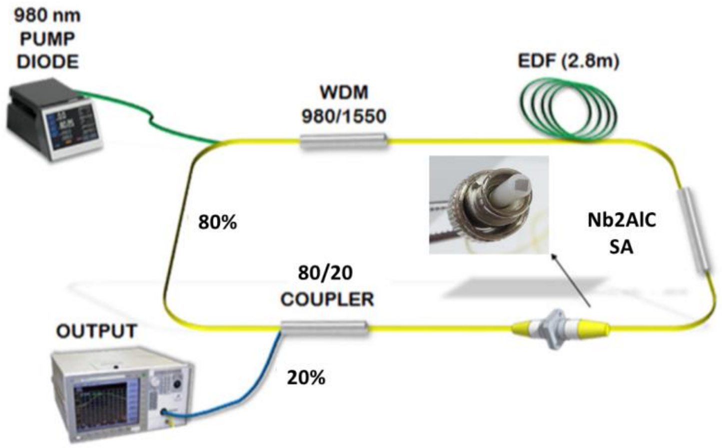


Fig. 1. 1.5-µm ring cavity setup

Figure 2 illustrates the normalized intensity-dependent transmission measurement data of modulation depth. According to the results of the fitting, the modulation depth, saturation intensity, and non-saturable absorption are approximately 28%, 0.08 MW/cm^2, and 64%, respectively. The prepared Nb_2AlC PVA thin film has a comparable modulation depth with other materials and can be used to initiate a mode-locked pulse.

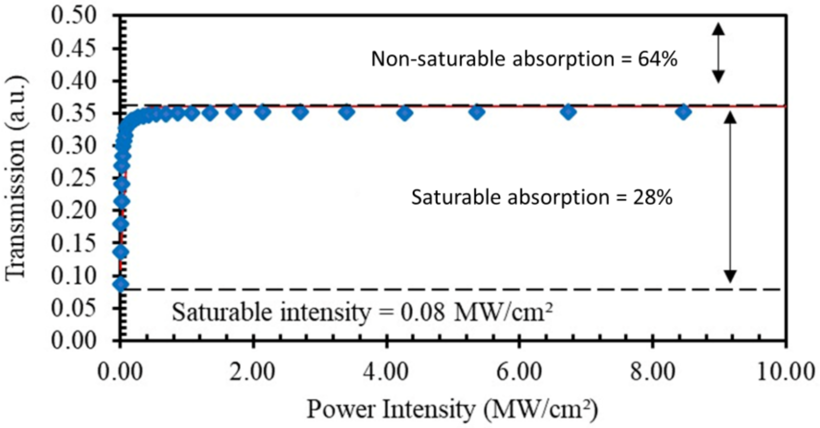


Fig. 2. Modulation depth

3. Results

As the input power of the pump laser diode was changed between 45.45 and 81.97 mW, passive Q-switched pulses were produced and remained steady. Figure 3 shows the output spectrum of the Q-switched EDFL as measured by an OSA at 81.97 mW of pump power over a span 100 wavelength range of 1480 nm to 1580 nm. According to the graph, the laser's spectrum shifted from 1564 nm to 1531 nm.

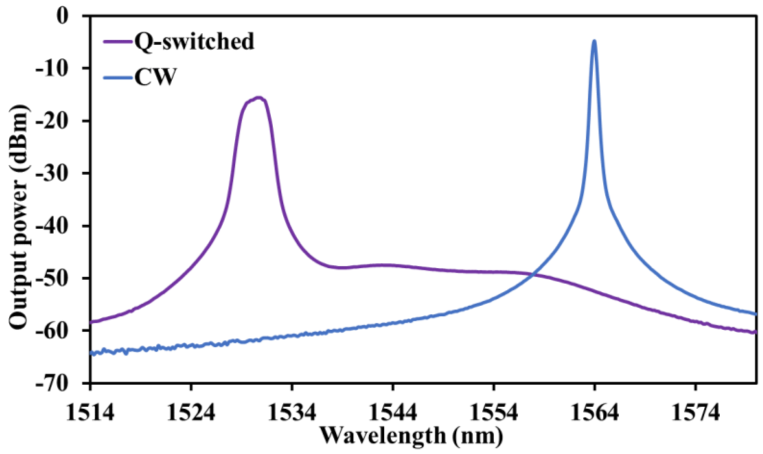


Fig. 3. Output spectrum of MAX-PVA

Using an RF spectrum analyzer, the steadiness of these pulses at the 81.97 mW pump power was also evaluated, as shown in Figure 4. Within a 2 MHz time span, the RF spectrum has captured a large number of harmonics across a wideband frequency range. The generated Q-switched signal has a signal-to-noise ratio (SNR) of 54.46 dB at 58.21 kHz fundamental frequency. The outcome shows remarkable Q-switching stability.

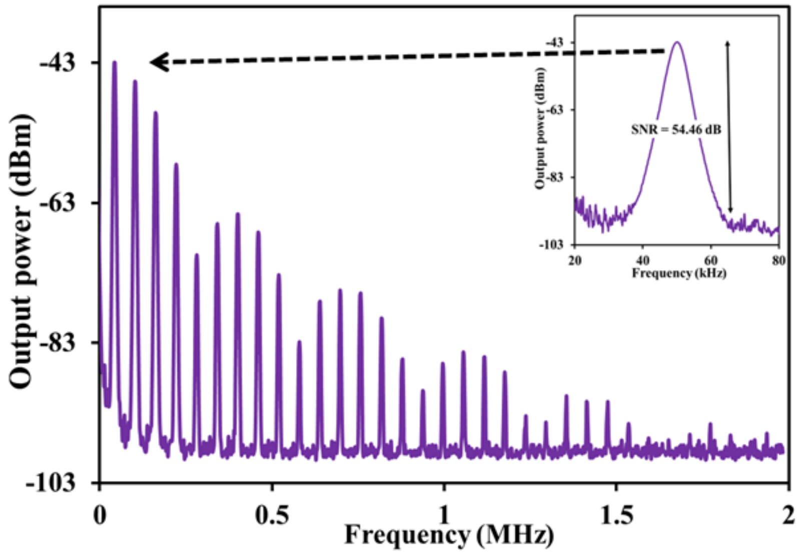
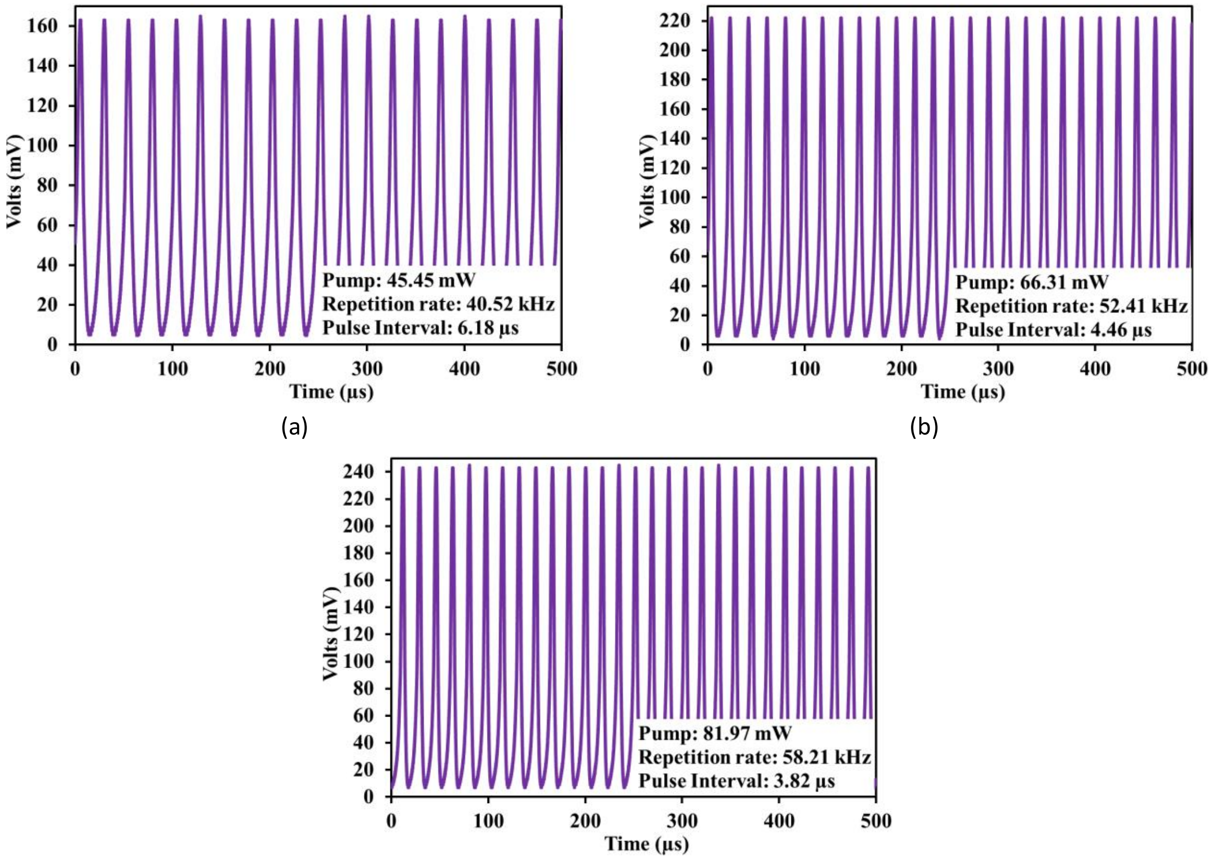


Fig. 4. RF spectrum with a 2 MHz span and SNR of 54.46 dB (inset)

As shown in Figure 5, the Q-switching pulse trains were steady and kept a consistent distribution over the 45.45 to 81.97 mW pump power range. When the pump power was set to 45.45 mW, Figure 5(a) shows a straightforward Q-switched laser pulse train taken from the digital oscilloscope trace. An oscillation of the pulse train occurs at a frequency of 40.52 kHz. According to Figure 5(b) and (c), the repetition rate was improved to 52.41 kHz and 58.21 kHz as the input pump's power was increased to 66.31 mW and 81.97 mW, respectively. On the other hand, as pump power increases, the pulse duration shortens.

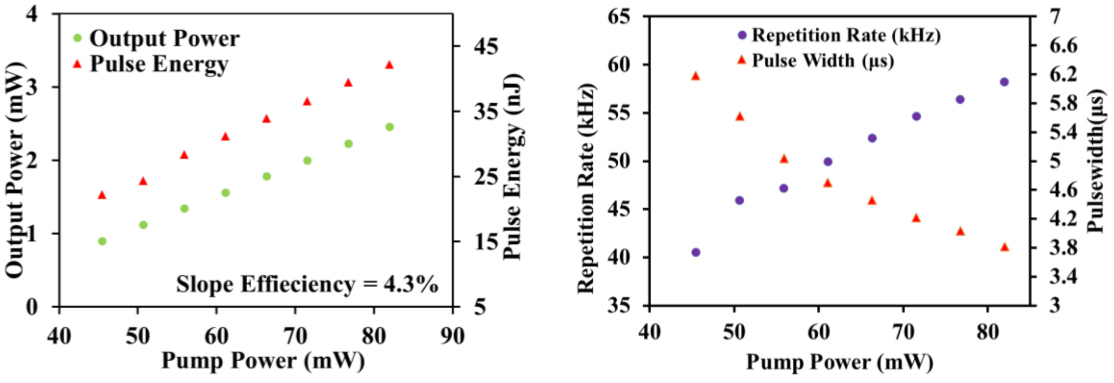
The steadiness of the Q-switching is demonstrated by the uniformity and stability of all the pulse trains. The Q-switching pulses became unstable and then vanished as we increased the pump power to more than 81.97 mW. The laser was converted to operate in CW mode up to 254 mW pump power. However, as soon as the pump power was decreased once more to less than 81.97 mW, the Q-switching operation was resumed. This shows that the 254 mW maximum power of the pump is below the damage threshold of the SA film. These results show that MAX phase Nb_2AlC, especially at low pumping strengths, is a suitable SA material for Q-switching applications.



(c)

Fig. 5. Oscilloscope pulse train at the pump power of (a) 45.45 mW (b) 66.31 mW (c) 81.97 mW

The results of the evaluation of pulse energy, average output power, repetition rate, and pulse width as functions of pump power are summarized in Figure 6. The average output power increased consistently from 0.9 mW to 2.46 mW, as shown in Figure 6(a), which graphs the output power and pulse energy versus the pump power. At a pump power of 81.97 mW, the greatest pulse energy of 42.26 nJ was obtained. The pump power is shown versus the pulse repetition rate and pulse width in Figure 6(b). The pulse width decreased from 6.18 to 3.82 s, leading the pulse rate to increase from 40.52 to 58.21 kHz, while the pump's output power increased from 45.45 to 81.97 mW. The linear relationships are expected for a Q-switched laser because the quantity of energy transferred to the cavity climbed as pump power rose until the SA got saturated.



(a) (b)

Fig. 6. (a) Output power against pulse energy (b) Repetition rate against pulse width

It can be seen from the suggested laser in this study that a passively SA based on Nb_2AlC has indeed been effectively constructed because it can produce a stable Q-switching output. Tremendous photonics application potential is also there with Nb_2AlC. Table 1 compares our Q-switched fiber laser's output performance to that of Q-switched fiber lasers operating at 1.5 m wavelengths with different MAX phases. The performance of our brand-new Nb_2AlC SA is comparable to other SAs. The Nb_2AlC SA has the second-smallest threshold pump power for Q-switched pulse production, with barely any change. The D-shaped Ti_3AlC_2 SA outperforms the Nb_2AlC SA with pulse energy obtained. This is most likely caused by the SA's high insertion loss.

Table 1

Performance comparison of passively Q-switched fiber lasers with various MAX phase-based SAs

SA Composition	Integration Method	Center Wavelength (nm)	Threshold (mW)	Repetition Rate (kHz)	Pulse Energy (nJ)	Pulse Width (μs)	Ref.
Ti_2AlC	Thin Film	1557	86.8	29.2	92.8	2.85	[20]
Ti_2AlN	Thin Film	1557	73	41.55	7.00	2.52	[21]
Cr_2AlC	Thin Film	1531	117	132	9.00	0.78	[22]
Ti_3AlC_2	Thin Film	1560.2	44	112	75	3.93	[23]
	D-shaped	1558.2	62	96.15	151.8	2.93	[23]
V_2AlC	Thin Film	1559	40.2	53.55	57.14	2.54	[24]
Nb_2AlC	Thin Film	1531	45.45	58.21	42.26	3.82	This work

4. Conclusions

Nb_2AlC, a novel MAX phase material, has been used to enable Q-switching in an Erbium-based fiber laser. Integration of the SA into erbium arrangement resulted in a pulse output with a pulse width and center wavelength of 3.82 s and 1531 nm, respectively, at a maximum pump power of 81.97 mW. Aside from having an output power of 2.46 mW, the pulses' energy was 42.26 nJ. The outcome suggests that Nb_2AlC has the potential to be used in laser applications. Due to the MAX phase material's benefits, which include outstanding antioxidants, high stability, and ease of fabrication, it is anticipated to become a formidable rival, particularly for application as practical SA.

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