Q-switched Ytterbium-doped fibre laser using an 8 cm long Hafnium bismuth erbium co-doped fibre saturable absorber

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Abstract. In this paper, we present a Q-switched fibre laser at 1069 nm which is induced by an 8 cm long Hafnium bismuth erbium co-doped fibre (HBEDF) saturable absorber (SA). The pulsating laser has a maximum repetition rate of 67 kHz at 175 mW pump power. We obtained the narrowest pulse width of 3.48 μs, the maximum pulse energy of 70.2 nJ, the maximum output power of 4.7 mW and the maximum peak power of 20.1 mW. The Q-switched laser is simple and may found practical applications in medicine and remote sensing.

Keywords: saturable absorber, pulsed fibre laser, passive method, ytterbium-doped fibre laser

1. Introduction
Q-switched fibre laser via passive technique has been quite popular in recent years due to its small size and simple fabrication, making it suitable for biomedical, material processing, and remote sensing applications [1, 2]. Semiconductor saturable absorber mirror (SESAM)[3], carbon nanotubes (CNTs) [4], and graphene [5, 6] are some of the early SAs with excellent performance. Later, many other SAs, have been demonstrated [7, 8]. However, most of the SAs are film-based since they are easy to prepare [9-14]. However, the film SAs have some issues, as they are easy to get oxidized, degraded, and burnt after certain days of usage.

Recently, our lab has demonstrated a few Q-switched lasers based on fibre SAs [15-19]. The fibre SA is flexible, simple, and has good similarities to the active medium, making it durable and easy to maintain.
This paper demonstrates a stable Q-switched ytterbium-doped fibre laser (YDFL) that uses an 8 cm long HBDEF as the passive SA. The Q-switched laser can be tuned from 41 kHz to 67 kHz by adjusting the pump power within the range of 106 mW to 175 mW.

2. Methodology

2.1. Saturable absorber preparation
The HBEDF was made by incorporating Hafnium (Hf), Bismuth (Bi) and Erbium (Er) element in a silica glass via a modified chemical vapour deposition process. The doping level of the fabricated fibre was checked through an electron-probe microanalysis. The result indicates the corresponding elements weight percentage as follows; 1.23 wt % of Er, 2.2 wt % of Hf and 0.035 wt % of Bi.

The fabricated fibre was cut into a short segment of 8 cm. Both ends of the fibre were then spliced with a single-mode fibre (SMF28), which gives a final SA dimension of (8 cm SMF28 – 8 cm HBEDF – 8 cm SMF28). However, for simplicity, we regard the fibre SA as 8 cm HBDEF SA. The linear absorption profile (LAP) was measured by placing the fibre SA between a white light source (WLS) and an optical spectrum analyzer (OSA) by considering the absorption value with and without the fibre SA. We noticed sufficient absorption of 3 dB at the Q-switched operating wavelength (1069 nm YDFL), as depicted in Figure 1.

2.2. Laser cavity configuration
The laser cavity consists of a laser diode pump (980 nm), a single-core ytterbium-doped fibre (YDF, 1.5 m), a 980/1060 wavelength division multiplexer (WDM), a 3 dB optical coupler, and the HBDEF SA. The arrangement of the laser cavity is depicted in Figure 2. The isolator keeps the unidirectional light propagation. The 3 dB coupler splits the light into a 50:50 ratio. Half of it is channelled into optical measurement devices such as OSA, a digital oscilloscope and a radio frequency spectrum analyzer (RFSA).
Figure 2. HBDEF SA based Q-switched laser cavity configuration

3. Results and discussion
The Q-switched YDFL based on the HDEF SA starts to appear at a threshold pump power of 106 mW. The pulsed laser has an initial repetition rate of 41 kHz. The pulse frequency monotonically increases to 67 kHz as the pump power rises to 175 mW. Beyond the 175 mW, the pulsed laser collapses into a continuous laser (CW). Figure 3 shows the Q-switched laser spectrum, centred ($\lambda_c$) at 1069 nm with a peak intensity of -15.2 dBm.

Figure 3. HBDEF SA based Q-switched laser spectrum at the 175 mW pump power
The Q-switched laser viewed in the time domain is shown in Figure 4. As illustrated, the generated pulse train has a frequency of 67 kHz, which reflects the pulse period of 14.9 μs. The pulse duration (τ) measured at the full width at half maximum (FWHM) is observed to be around 3.48 μs.

We also measured the radio frequency spectrum of the Q-switched laser. We observed consistent frequency harmonics, with a fundamental frequency (FF) of 67 kHz, the same as the one revealed in the time domain. Furthermore, the signal to noise ratio (SNR=48 dB) is considerably high, suggesting that the generated Q-switched laser is stable.

![Figure 4](image)

**Figure 4.** HBDEF SA based Q-switched pulse train at the 175 pump power

4. Conclusion
We demonstrated a Q-switched fibre laser at 1069 nm by integrating an 8 cm long HBDEF SA. The pulsed laser has the shortest pulse width of 3.48 μs and the maximum pulse frequency of 67 kHz at the 175-mW pump power. The maximum pulse energy is 70.2 nJ. The Q-switched laser is simple, flexible and can be used in many applications, including biomedical and material processing.

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