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Passively Q-switched Fiber Laser Using Nanomaterials as a Saturable Absorber

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Abstract

Pulsed laser possesses attractive optical characteristics because of its high-energy photons, wide absorption range, and effective thermal management. These benefits make them suitable for various applications, particularly in scientific research, electronic devices, industry, medical treatment, and the military. A fiber laser with Q-switching, capable of generating short and energetic pulses by manipulating the losses within the laser resonator, is a valuable technique for achieving microsecond pulse durations. Within this study, an erbium-doped fiber laser (EDFL) with passive Q-switching was created employing Saturable Absorbers (SAs) composed of calcium carbonate ($CaCo_3$) and boron carbide (B_4C) nanoparticles. The fabrication involved the drop-casting method, with polyvinyl alcohol (PVA) serving as the host polymer, owing to its high ability to produce film with high flexibility. The SA materials were characterized using different techniques to determine their optical and physical spectroscopic analyses, including surface morphology examination, and measurement of the SA material modulation depth. Their crystalline structure was examined using X-ray diffraction (XRD) analysis, the morphological arrangement was measured by field emission scanning electron microscope (FESEM), and the optical characteristics were found using UV-Vis spectrophotometer (regarding linear optical characteristics) and the Z-Scan technique for the absorption that is nonlinear including the measurement of modulation depth. The Q-switched EDFL's performance was evaluated utilizing $CaCo_3$/PVA and B_4C/PVA (films)-based SAs in the same arrangement of the ring cavity. A numerical simulation of the Q-switching process in a fiber cavity with an SA was performed in this study. The SA dynamics in the Q-switched laser model were considered. The pump power was used to compute the pulse duration, repetition rate, and peak power. Studies have been carried out on the effects of every component in the cavity and the pulse characteristics of the fiber laser arrangement. The output parameters of

the Q-switched EDFL in passive mode were analyzed, including the pulse duration, pulse repetition rate, pulse energy, pulse train, output spectrum, and signal-to-noise ratio.

The results indicated the operation of a dual-wavelength passively Q-switched EDFL that incorporates $CaCO_3$ nanoparticles as SA. The film was integrated into a ring laser cavity with a 976 nm pump to generate Q-switched pulses. The properties of the SA were examined experimentally, and its modulation depth is approximately 47%. As the pump power increased from 180 mW to 270 mW and the pulse repetition rate increased from 12.67 kHz to 21.3 kHz, the corresponding pulse width decreased from 35.27 μs to 18.74 μs. The signal-to-noise ratio was approximately 25 dB, highlighting the laser's stability.

As well as using boron carbide nanoparticles (B_4C) as SA for producing pulses by a fiber laser operating in Q-switched mode. The modulation depth of the B_4C-SA was 2.3%. Stable Q-switching laser operation was accomplished with 180 mW pump power and 1563.2 nm central wavelength by producing laser pulses with a 31.6 kHz repetition rate and 15.27 μs pulse duration. A comparable pulse energy achieved with 275 mW maximum pump power was approximately 2.61 nJ. The radio-frequency spectrum was examined to verify the pulse stability. The study showed a signal-to-noise ratio of 35 dB.

These results expand the potential of $CaCo_3$ and B_4C-based saturable absorbers, making them strong contenders for innovative photonic devices.