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Vector soliton and noise-like pulse generation using a Ti_3C_2 MXene material in a fiber laser

Key words: Vector soliton; Noise-like pulse; MXene; Laser fiber

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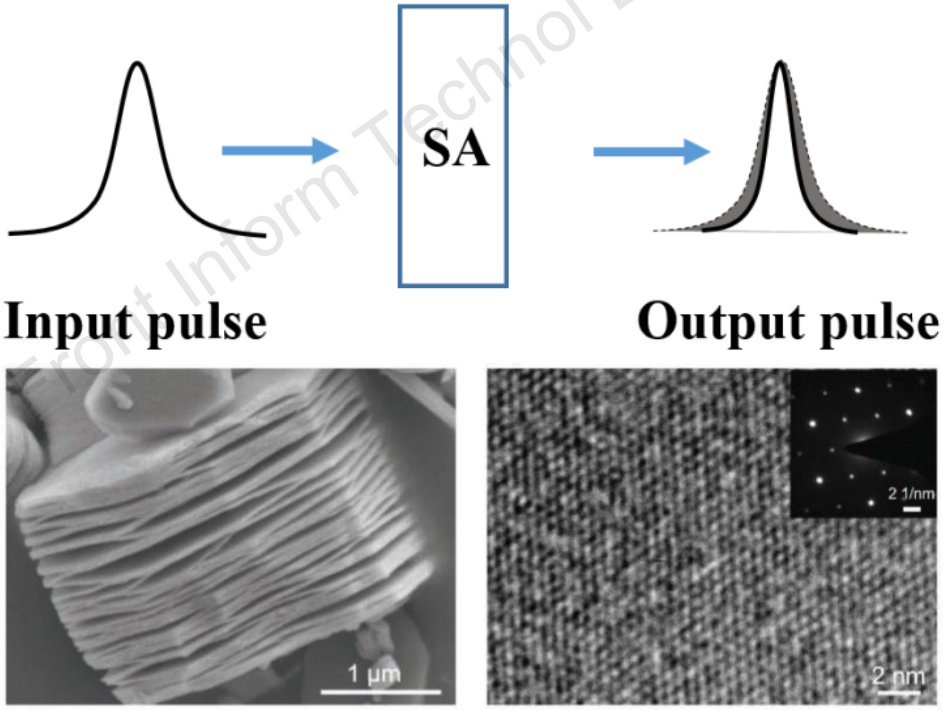
MXene research progress

- Two-dimensional (2D) materials (e.g., MXene) have attracted extensive attention in materials science due to their excellent properties.

Date	Event
2015.6	A new type of 2D material known as MXene, composed of elements such as transition metal carbides, nitrides, and carbonitrides, arouses the interest of researchers due to the good electrical conductivity, high elastic modulus, high capacitance, tunable band gap, and high optical transmission.
2016.4	Gogotsi's team produced a transparent $Ti_3C_2T_x$ MXene film with optoelectronic tunable characteristics.
2018.6	Feng et al. (2018) used an MXene as a saturable absorber (SA) for the first time to achieve passive Q-switching at 1060 nm in a Nd:YAG ceramic laser.
2018.9	Researchers achieved Q-switching and highly stable femtosecond pulse mode-locked fiber lasers in the near-infrared communication band to the short-wave infrared band using $Ti_3C_2T_x$ MXene as an SA.
2019.5	Jiang Q et al. (2019) integrated a microfiber-based $Ti_3C_2T_x$ MXene SA to achieve soliton mode-locking with a pulse duration of 2.11 ps at 2 μm for the first time in a Tm-doped all-fiber laser.

Tendency and challenges

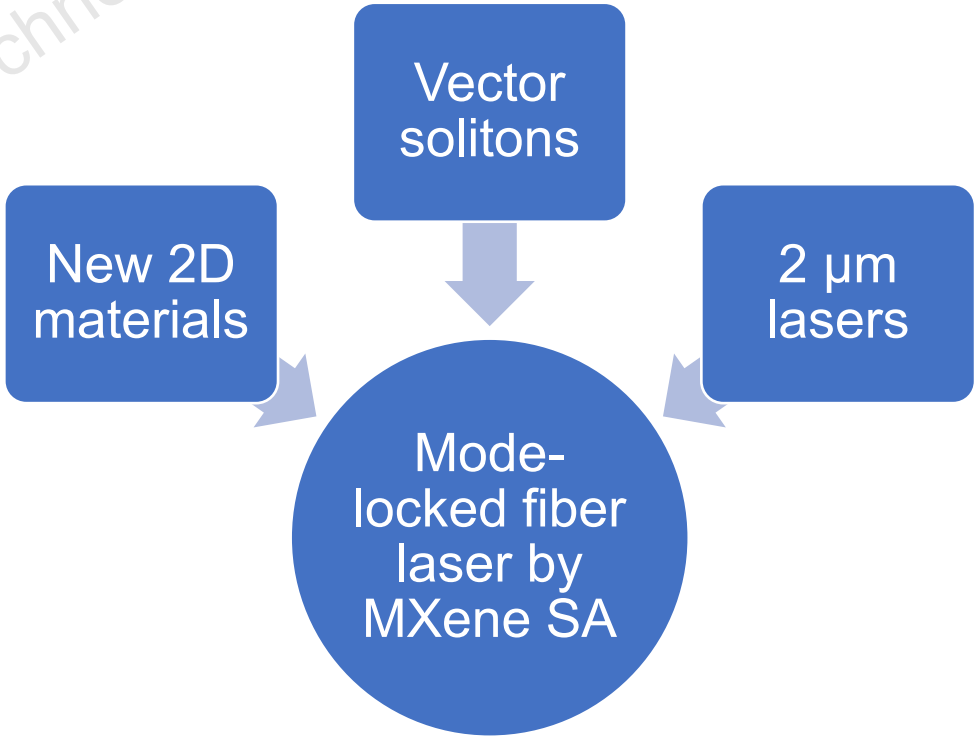
- Mode-locked fiber lasers that use a 2D material SA have the capability of generating pulses with narrow pulse width, high peak power, and abundant dynamic phenomena. However, due to the loss in the 2 μm band, there are few reports on the soliton dynamics of fiber lasers that use 2D material SA to achieve mode locking in this band.



Wang et al. (2019)

Motivation

- Two-dimensional (2D) materials have attracted extensive attention in materials science due to their excellent properties. Therefore, as a new type of 2D material, the optical properties of MXene deserve to be studied.
- Due to the strong absorption of water, 2 μm laser is widely used in the medical field (Scholle et al., 2010). But so far, there are few reports on the study of mode-locked fiber lasers using MXene as an SA in the 2 μm band.
- Vector soliton is of great significance in modern communication and nonlinear optics research. 2D material mode-locked fiber laser is an important platform for the study of vector soliton.



1) Fabrication and properties of Ti_3C_2 MXene SA

- The liquid acid etching exfoliation method is a common method for converting layered bulk materials into ultra-thin 2D materials.
- The side-polished D-shaped fiber is always used to add 2D materials to made SA.

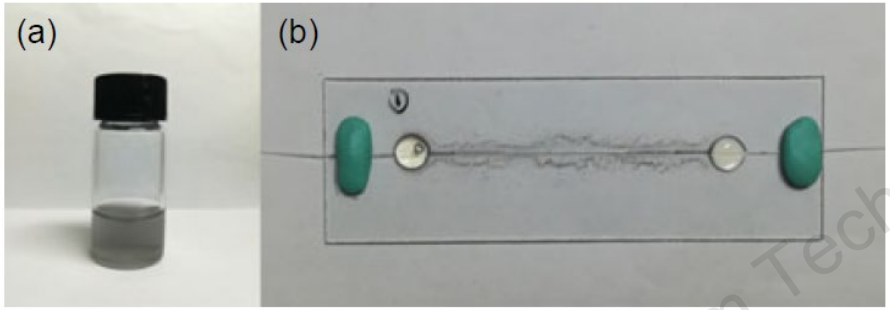


Fig. 1 Schematic of the Ti_3C_2 MXene solution (a) and homemade saturable absorber (SA) (b)

Fig. 2 D-shaped fiber photographed by the depth-of-field extension function of the microscope

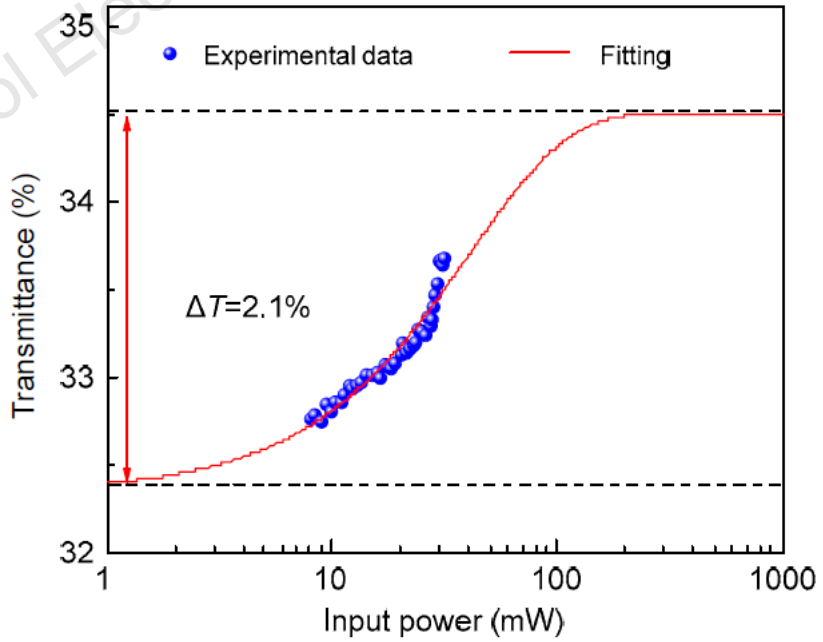


Fig. 3 Nonlinear saturable absorption of the Ti_3C_2 MXene saturable absorber (SA)

2) Building mode-locked fiber laser with MXene SA

- Integrate the homemade MXene SA into a ring fiber laser, and achieve mode locking by adjusting the polarization controller in the cavity.

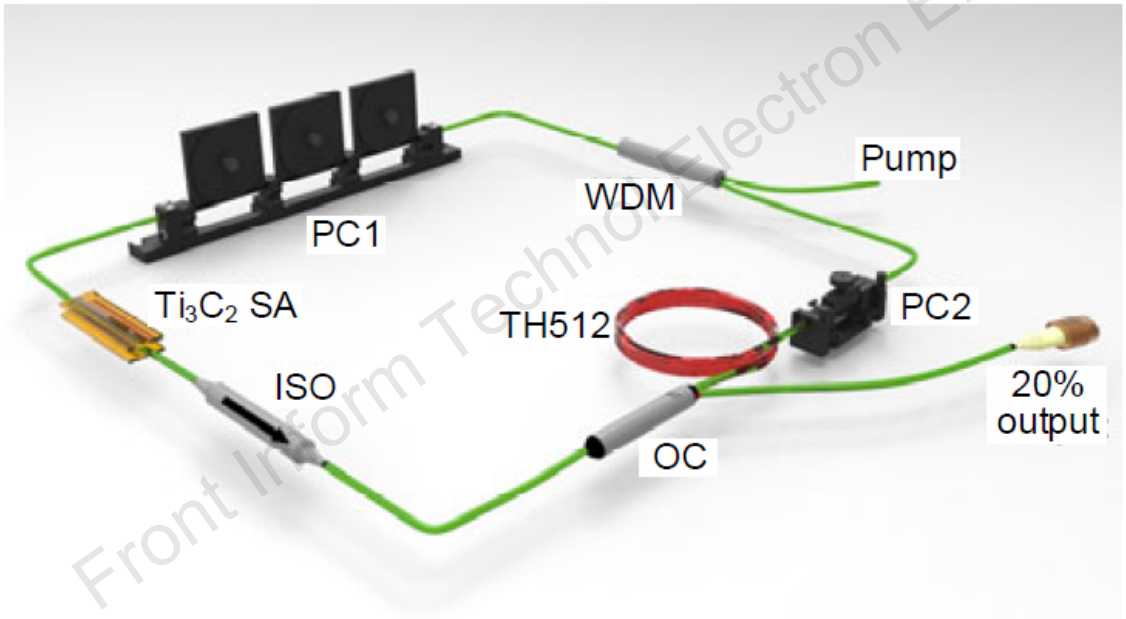


Fig. 4 Schematic of the fiber laser

WDM: wavelength division multiplexer; PC: polarization controller; ISO: isolator; OC: output coupler; TH512: Thulium/Holmium-doped fiber; Ti_3C_2 SA: side-polished D-shaped fiber Ti_3C_2 saturable absorber

3) Vector solitons obtained by MXene fiber laser

- When the pump power reached 1.13 W, the mode-locking pulse with two sets of Kelly sidebands could be obtained in the laser cavity, which is a sign of a typical vector soliton (Song et al., 2012, 2019). It is a state of harmonic mode locking with the order of 19.

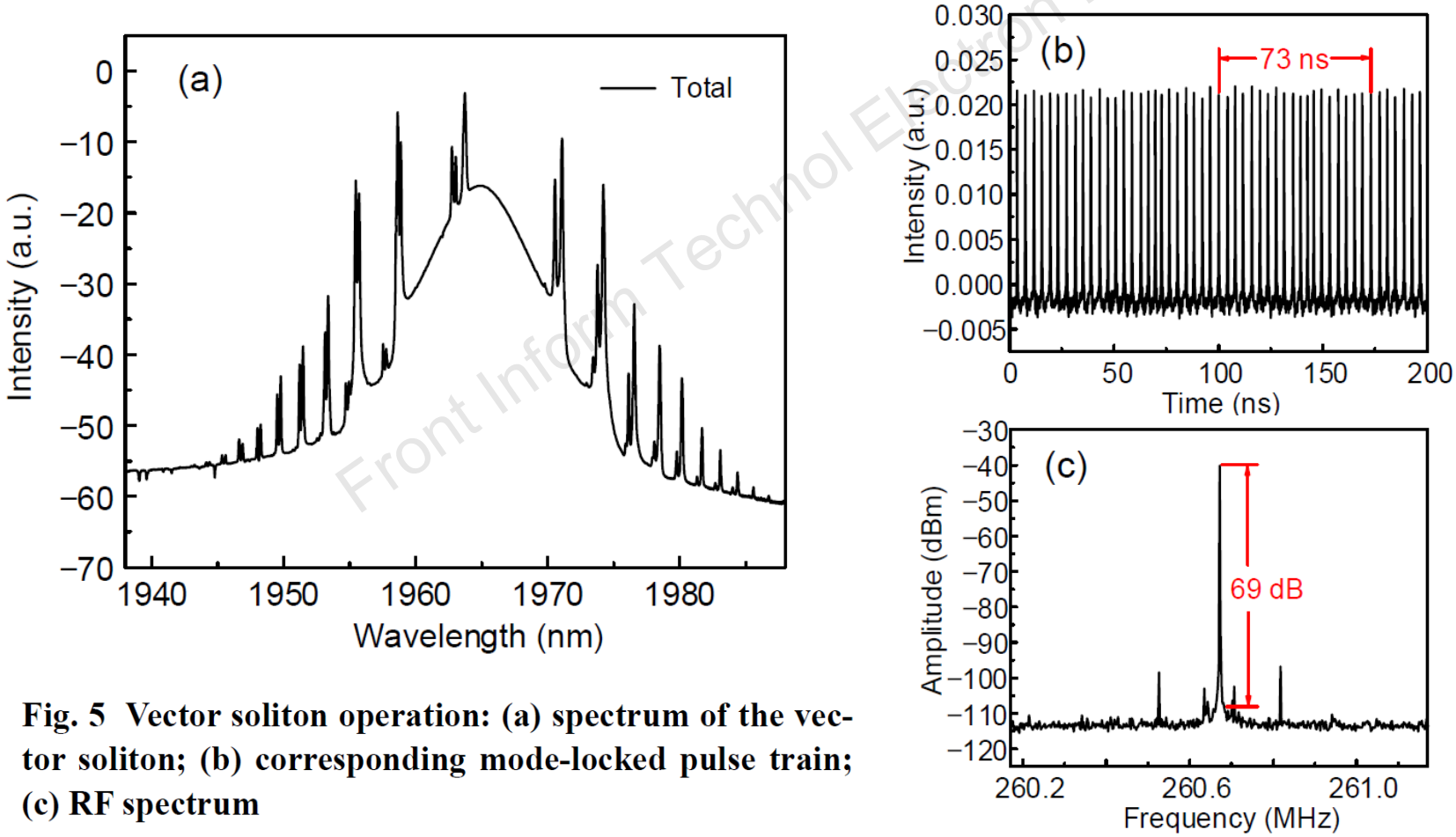


Fig. 5 Vector soliton operation: (a) spectrum of the vector soliton; (b) corresponding mode-locked pulse train; (c) RF spectrum

3) Vector solitons obtained by MXene fiber laser

- To explore the vector characteristics, we used a polarization beam splitter (PBS) and a polarization controller (PC) at the output of the cavity to resolve the output into two beams whose polarization are orthogonal to each other.

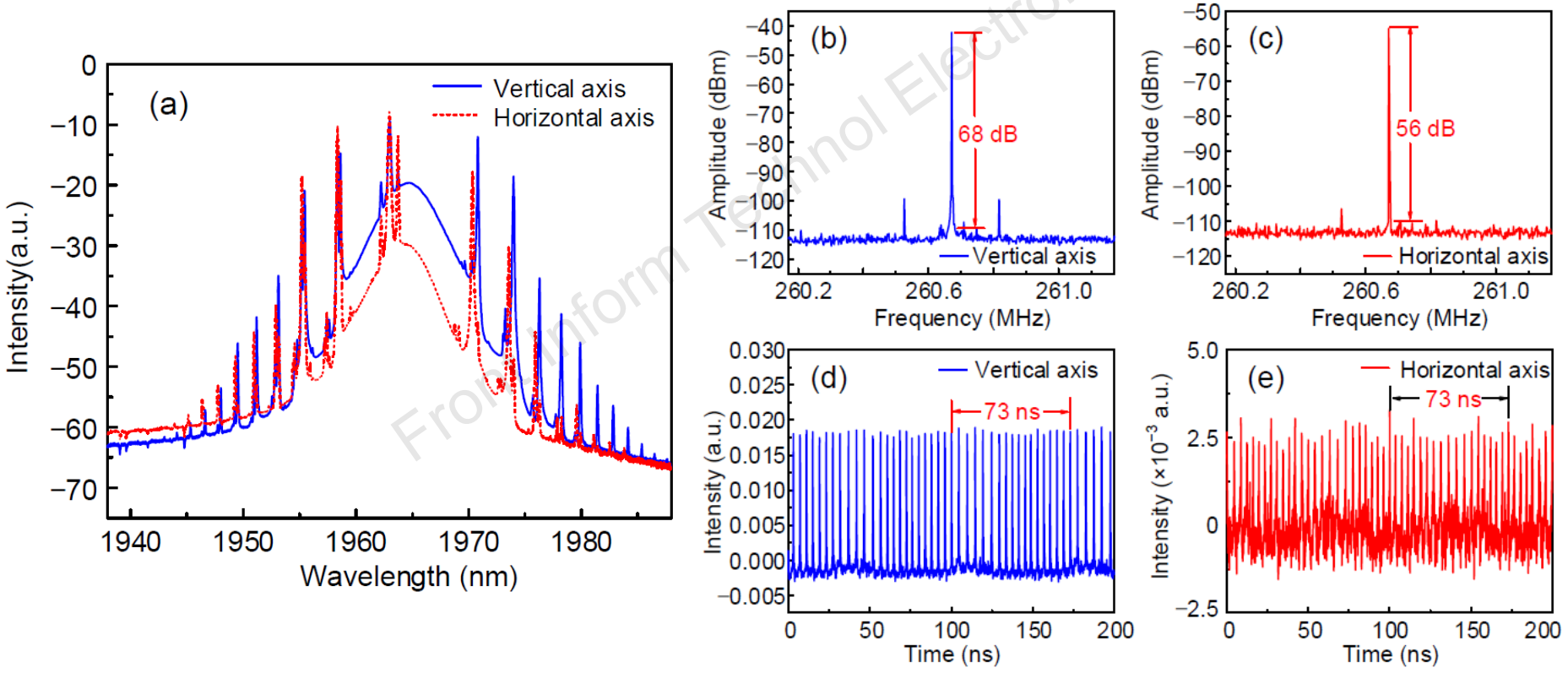


Fig. 6 Vector soliton operation after splitting of the polarization beam splitter (PBS)

4) Noise-like pulses obtained by MXene fiber laser

- Careful adjustment of the polarization controller could gradually transform the vector solitons into noise-like pulses while keeping the pump power constant.

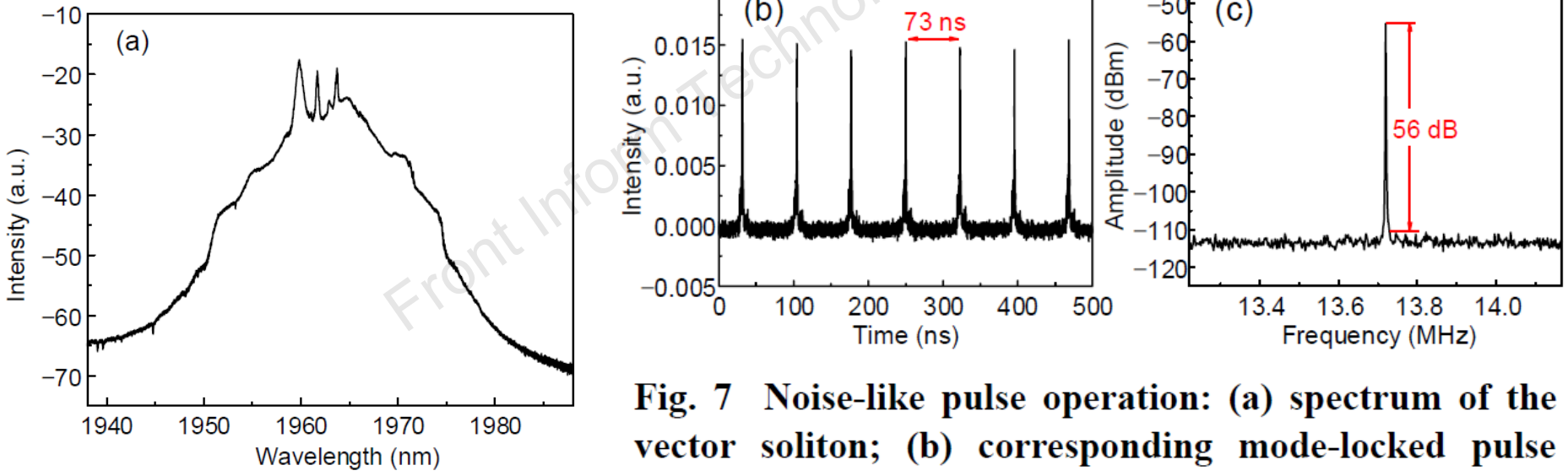


Fig. 7 Noise-like pulse operation: (a) spectrum of the vector soliton; (b) corresponding mode-locked pulse train; (c) RF spectrum

Future outlook

MXene SA fiber laser research	Outlook
Other bands	This work studied only the vector characteristics of MXene SA in the 2 μm band. This material has a wide absorption peak and can achieve mode locking in multiple bands; the vector characteristics in other bands are still to be verified.
Topological insulators (TI) based on MXene	Noise-like pulse (NLP) is usually caused by the collapse of the soliton in the cavity, which is undesirable for fiber lasers that produce narrow bandwidth and high repetition rate. According to a number of experimental studies of previous researchers, it is possible to achieve a stable pure soliton state without NLP in a mode-locked fiber laser using a 2D material of a topologically insulating Bi_2Se_3 film (Miao et al., 2019). TI based on new materials similar to MXene is expected to become an all-optical switch and high-quality SA material, which is worthy of further research and exploration.

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