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- Electronic Supplementary Material (ESI) –

TiB_2 nanoparticles with broadband nonlinear response for ultrafast pulses generation

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Preparation of TiB_2 NPs

A metal-hydrolysis-assisted synthesis (MHAS) strategy was used to fabricate the TiB_2 NPs. TiO_2 (0.01 mol), amorphous boron powder (0.03 mol) and Mg powders (0.12 mol) were homogeneously mixed into a 20 mL stainless steel autoclave, and then 10 mL of distilled water was added. Subsequently, the autoclave was sealed and heated from room temperature to 150 °C at a rate of 10 °C min-1 and kept for 2 h. After that, the autoclave was allowed to cool naturally, and the raw materials were washed in turn with hydrochloric acid (0.2 mol/L), distilled water, and ethanol and, through centrifugal processing, finally dried in a vacuum oven at 60 °C for 8 h. Finally, black gray powders were obtained.

Experiment setup for the nonlinear absorption measurement

Figure S2 depicted the balanced synchronous dual-detector power measurement system for the measurement of the nonlinear saturable absorption.

The self-made pulsed lasers operating at 1.56 and 2 μm were used as the light source, which possessed central wavelengths of 1559 nm/1980 nm, a pulse duration of 1.28 ps/562 fs, and a repetition frequency of 54 MHz/25 MHz. A 50:50 beam splitter was used to divide the light into two beams through the TiB_2-SPF SA and bare SPF, which were used as test light and reference light, respectively.

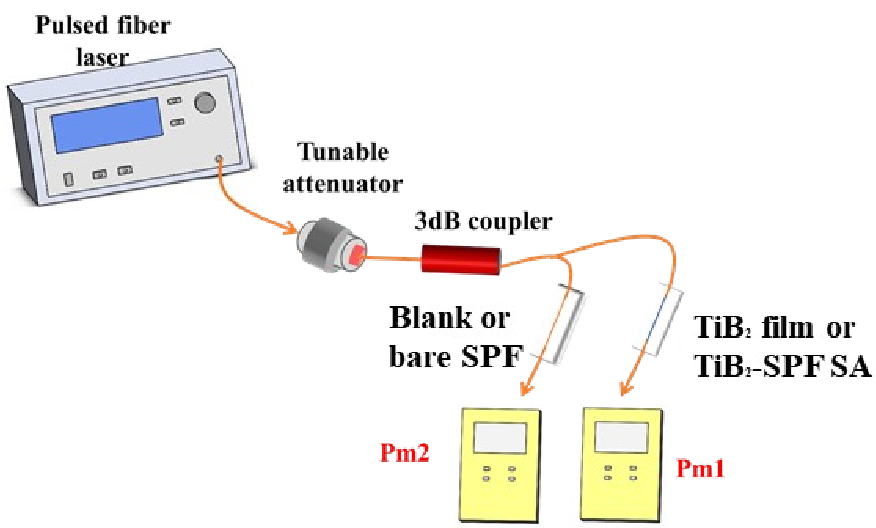

Fig. S1 Measurement system for the nonlinear absorption.

Saturable absorption property model for the measured data

The following equation was used to fit the measured data.

$$\alpha(I)=\frac{\alpha_S}{1+I/I_S}+\alpha_{NS} \quad (1)$$

where the parameters (*a_S, a_{NS} and I_S*) are the modulation depth, nonsaturable loss, and saturation power density, respectively.

Erbium-doped fiber laser with TiB_2 film SA

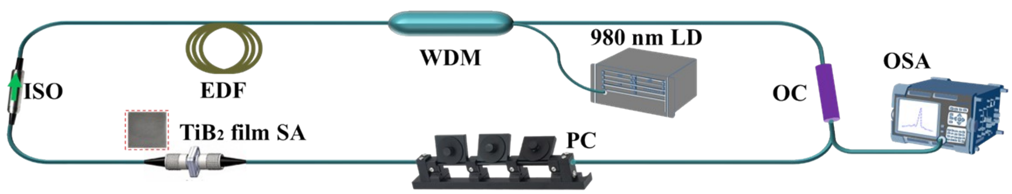

Fig. S2 Experimental setup of the erbium-doped fiber laser ring cavity.

The pump light was a 980 nm laser diode (LD), which would be launched into the cavity through a 980/1560 nm wavelength-division multiplexing (WDM) coupler. A 20-cm-long erbium-doped fiber (EDF) was utilized as the gain medium. An isolator (ISO) was added to avoid any harmful feedbacks. A polarization controller (PC) was put into the cavity for the optimum polarization state. The 10 dB optical coupler (OC) was adopted to output 10% of the laser and the rest continued propagating in the cavity. The TiB_2 film was integrated between the fiber connectors. The output end of the 10 dB OC was connected to an optical spectrum analyzer (OSA) to present the laser spectrum.

Calculation of the evanescent field intensity

The field strength of fiber evanescent field can be expressed as follows:

$$E=E_0 exp(-z/d_p) \quad (2)$$

Where, E_0 is the energy intensity of evanescent field at the interface, z is the distance from the field point to the interface, and d_p is the penetration depth of evanescent field. d_p is defined as the distance between the field point and the interface when the intensity of the energy field drops to $(1/e)E_0$. The equation is expressed as follows:

$$d_p = \lambda \Big/ \left(2\pi\sqrt{n_1^2 sin^2\theta - n_2^2}\right) \tag{3}$$

Where, λ is the wavelength of light when it propagates in a vacuum, n_1 is the refractive index of the optical fiber core, n_2 is the refractive index of the fiber cladding, and θ is the incident angle of light at the interface. It can be seen that the intensity of evanescent field of the same SPF is positively correlated with the wavelength. By substituting the relevant parameters of SPF (SMF-28e) into Equations (2) and (3), we can get the relationship between the intensity of evanescent field on the external surface of SPF and the wavelength (Fig.S5).

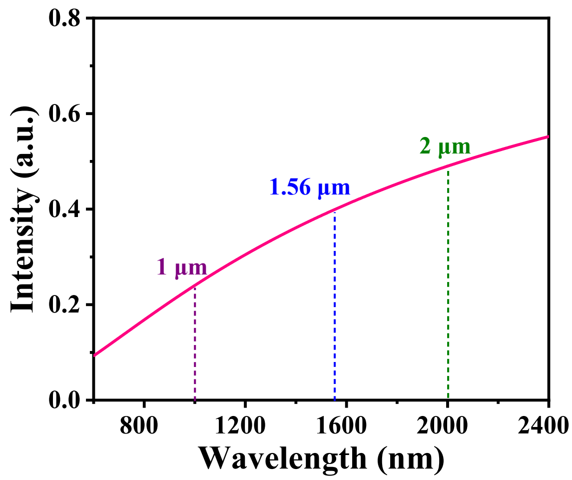

Fig. S3 Relationship between the intensity of evanescent field and the wavelength.

Erbium-doped fiber laser with TiB_2-SPF SA

The pump light was a 980 nm LD, which would be launched into the cavity through a 980/1560 nm WDM coupler. A 20-cm-long EDF was utilized as the gain medium. An ISO was added to avoid any harmful feedbacks. A PC was put into the cavity for the optimum polarization state. The 10 dB OC was adopted to output 10% of the laser and the rest continued propagating in the cavity. The TiB_2-SPF SA was integrated into the laser cavity. The output end of the 10 dB OC was connected to an OSA to present the laser spectrum.

Thulium-doped fiber laser with TiB_2-SPF SA

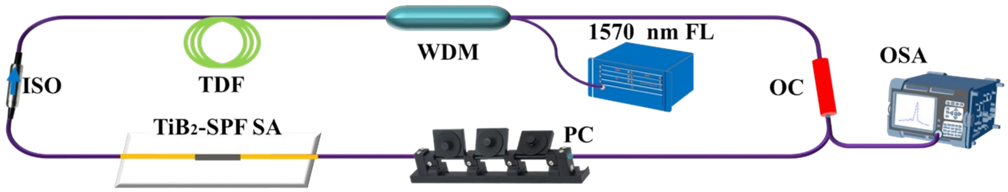

Fig. S4 Experimental setup of the thulium-doped fiber laser ring cavity.

The pump light was a 1570 nm fiber laser (FL), which would be launched into the cavity through a 1550/2000 nm WDM coupler. A 20-cm-long thulium-doped fiber (TDF) was utilized as the gain medium. An ISO was added to avoid any harmful feedbacks. A PC was put in the cavity for the optimum polarization state. The 10 dB OC was adopted to output 10% of the laser and the rest continued propagating in the cavity. The TiB_2-SPF SA was integrated between the fiber connectors. The output end of the 10 dB OC was connected to an OSA to present the laser spectrum.

Spectral and temporal properties with a bare SPF

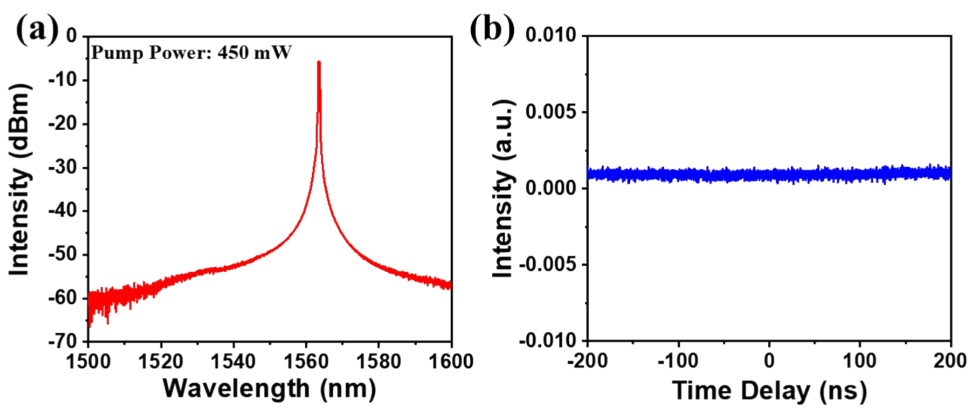

Fig. S5 (a) Emission spectrum and (b) pulse train of the EDFL with a bare SPF.

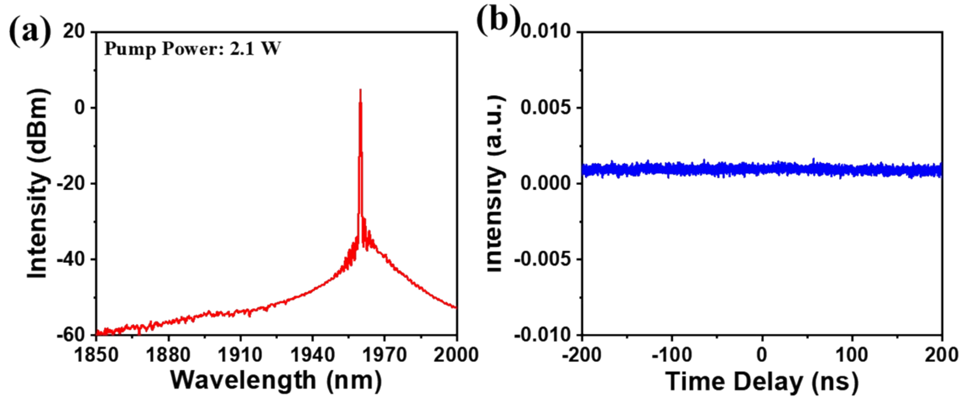

Fig. S6 (a) Emission spectrum and (b) pulse train of the TDFL with a bare SPF.