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► **To cite this version:**

Rémi Soulard, Ahmed Nady, Pavel Loiko, Franck Joulain, Ammar Hideur, et al.. Upconversion pumping of 808 nm Tm:ZBLAN fiber amplifier for gravitational wave detector laser sources. OPTIQUE Normandie 2024, Jul 2024, Rouen, France. hal-04663338

**HAL Id: hal-04663338**

**<https://hal.science/hal-04663338v1>**

Submitted on 27 Jul 2024

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# Upconversion pumping of 808 nm Tm:ZBLAN fiber amplifier for gravitational wave detector laser sources

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## ABSTRACT

We present a concept of 808 nm Tm:ZBLAN fiber amplifier based on high brightness upconversion pumping at 1064 nm. An amplification has been demonstrated experimentally and simulations show a maximum efficiency of about 45%. A bright and powerful 808 nm source is interesting for pumping Nd:YVO<sub>4</sub> amplifiers for gravitational wave detectors.

**KEYWORDS:** *fiber amplifier; thulium ions; fluoride fiber.*

## 1. INTRODUCTION

The future challenge for gravitational wave detectors is to lock the interferometer with more power inside. Hence, a more powerful source is necessary achieving up to 700 W at 1064 nm for Einstein Telescope for instance. Fiber technology could be a solution, but proof has not been made so far. Bulk amplifiers representing robust technology in the long-term scale with sensitivities around 50 Mpc in Virgo and 100 Mpc in LIGO have already been obtained.

Using a bright pump source at 808 nm could enable one to use longer bulk crystals mitigating thermal issues and keeping the bulk design still interesting. This bright pump source could be obtained based on Tm<sup>3+</sup>-doped fibers through the <sup>3</sup>H<sub>4</sub> → <sup>3</sup>H<sub>6</sub> transition. The energy-level scheme of Tm<sup>3+</sup> ions is depicted in Fig. 1(a). It shows several ways to excite ions from the ground state <sup>3</sup>H<sub>6</sub> to the <sup>3</sup>H<sub>4</sub> manifold via pumping at 680 nm, 790 nm (in-band pumping), or 1064 nm (upconversion pumping). Tm:ZBLAN fibers show a long <sup>3</sup>H<sub>4</sub> lifetime as compared to those for Tm<sup>3+</sup>-doped silica fibers, and therefore they are of interest for amplifiers around 808 nm. There exist only a few reports on Tm-fiber based sources around 800 nm, in which small-signal gain studies and laser operation reaching Watt-level output have been reported [1-3]. In the present work, we introduce a concept of 808 nm Tm:ZBLAN fiber amplifier system using 1064 nm Yb-fiber laser as pump source. Due to the brightness of the pump, the fiber can be core pumped, and high efficiency could be achieved.

## 2. EXPERIMENTAL SETUP

The schematic diagram of the Tm:ZBLAN fiber amplifier is shown in Fig. 1(b). The pump laser was a 1064-nm Yb-fiber laser delivering a maximum incident pump power of 6 W. The pump radiation was focused by an in-built collimator, passed through an optical isolator, a half-wave plate and a polarizer to control the incident pump power. The signal beam from a Ti:Sapphire laser and the pump beam were simultaneously injected into the fiber via a dichroic mirror (DM) and focused by an injection lens. A Tm:ZBLAN fiber with a doping level of 3 mol% Tm (*Le Verre Fluoré*) was used. The fiber core diameter was 13 μm.

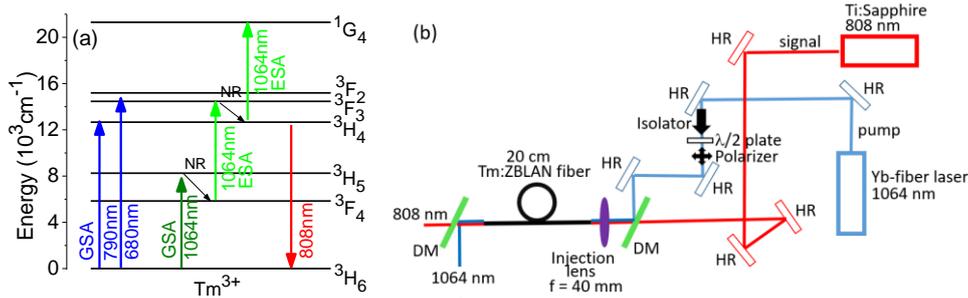


Figure 1: (a) Energy-level diagram of  $Tm^{3+}$  ions; (b) Layout of the fiber amplifier system.

### 3. RESULTS AND DISCUSSION

The simulation results of the proposed 808-nm Tm:ZBLAN fiber amplifier are presented in Fig. 2(a). A fiber length of 60 cm and an injected signal power of 100 mW are considered. The simulation shows that it is possible to obtain an optical efficiency of 45% under core pumping at 1064 nm. However, to achieve this, parasitic lasing at 1.9  $\mu m$  must be hindered. Theoretically, the fiber absorbs around 90% of the incident pump in line with the experimental observation (about 85%). The laser action at 1.9  $\mu m$  detrimentally affects the efficiency of the amplifier system at 808 nm. A preliminary gain measurement is shown in Fig. 2(b) highlighting the potential of the designed system for high-power amplification at 808 nm.

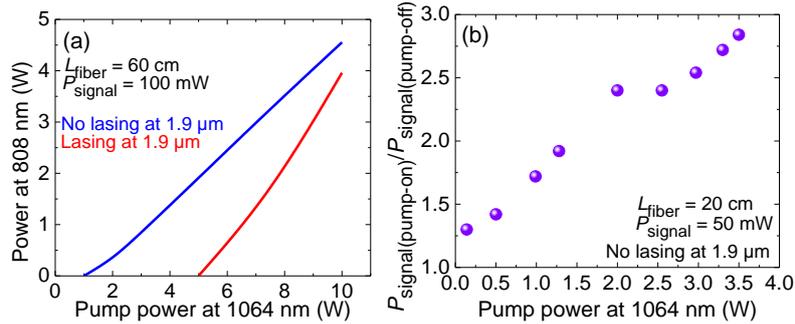


Figure 2: (a) Simulation of the output power from the amplifier at 808 nm as a function of the pump power at 1064 nm for a 60 cm-long Tm:ZBLAN fiber; (b) a preliminary gain measurement at 808 nm.

### 4. CONCLUSIONS

In conclusion, we have introduced the concept of a Tm:ZBLAN fiber amplifier system at 808 nm based on upconversion pumping using a Yb-fiber laser at 1064 nm. Theoretically, an efficiency of about 45% can be achieved under core pumping at 1064 nm provided that 1.9  $\mu m$  lasing does not affect the amplifier efficiency and possible Q-switching effects are mitigated. In-band pumping will also be investigated to reduce the quantum defect paving the way towards a high-power pump source for 1064-nm Nd-sources employed in highly sensitive gravitational wave detectors.

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