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# First demonstration of laser emission from an Yb:YAG Single Crystal Fiber grown by the Micro-Pulling Down technique

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**Abstract :** We present the first laser demonstration obtained from an Yb:YAG single-crystal fiber directly grown by the micro-pulling-down technique, with 2.2-W of average output power at 1031-nm for 50-W of incident pump power at 940-nm.

## 1. Introduction

An Ytterbium-doped gain laser medium that would benefit from the spectroscopic and thermal properties of bulk crystals and the good thermal management of glass fiber will be an ideal candidate to achieve high average power and high peak power laser systems. With the conventional growing techniques such as Czochralski process, the design of such crystal fibers requires costly and difficult engineering processes. Nevertheless, efficient results with a 2×50 mm<sup>2</sup> rod with undoped end caps [1] or a 1.2×20 mm<sup>2</sup> micro-rod tunable Yb:YAG laser have already been achieved [2]. Ceramic technologies are also a promising way to obtain thin and long materials with excellent optical qualities. In fact, a composite ceramic 1×1×42 mm<sup>3</sup> Yb:YAG was recently presented to design a high average power regenerative amplifier [3]. The micro-pulling-down technique [4] and the Laser Heated Pedestal Growth [5] are two conventional techniques to obtain single-crystal fibers far cheaper than the former techniques. Former works have shown the feasibility of growing Yb:YAG but no laser emission has been achieved due to a poor optical quality [6]. The recent developments of the micro-pulling down technique have opened a promising way in power scaling of lasers systems. In fact, the high potential of Nd:YAG single crystal fibers has already been demonstrated for the generation of high average power and high peak power with an excellent thermal management [7]. The use of Yb<sup>3+</sup>-doped materials allows a reduction of heat generation and better optical-to-optical conversion efficiency compared to Nd<sup>3+</sup>-doped single crystals optically pumped lasers. Moreover, the growing processes are remarkably efficient with Yb:YAG and very interesting because of the absence of longitudinal segregation [6].

We present here the first demonstration of laser emission from a directly grown single Yb:YAG crystal fiber.

## 2. Design and characterizations of the gain medium

The aim of this preliminary work is to design a high power system. In order to dispatch the thermal load along the crystal fiber, a low doping concentration and a long medium in which the pump is guided is required. Thus, we decided to design a single crystal fiber of 50 mm long and 1 mm diameter.

The quasi-three level structure of Yb<sup>3+</sup> transition requires a careful trade-off between length and doping rate in order to avoid important losses due to re-absorption at the laser wavelength emission. We have developed a numerical model for the simple pass small-signal gain of the medium by taking into account the saturation absorption effects. The model allows us to determinate the appropriate concentration in ions Yb<sup>3+</sup>. As shown in Fig.1, 0.3 at.% is the best value for a maximum incident pump power of 50 W at 940 nm which give us a theoretical simple pass small-signal value of 1.62. After the growing process, the single crystal fiber was cut and both ends surfaces were polished and antireflection coated at 940 and 1030 nm. We measured a transmission better than 99 % with a probe beam at 633 nm and with a waist of 200 μm in diameter. The guiding efficiency was measured by using the pumping scheme shown on Fig.2 with a fiber coupled laser diode at 808 nm, outside the absorption spectrum. 80 % of the incident power is guided by total internal reflection without any additional manufacturing processes on the cylinder.

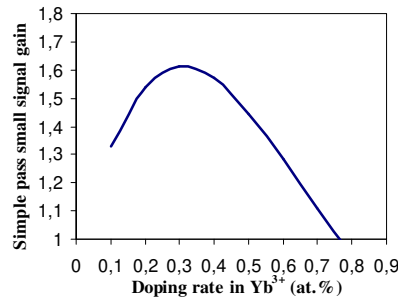


Fig.1. Evolution of the simple pass small-signal gain calculated at 1030 nm as a function of Yb<sup>3+</sup> doping concentration for 50 W of incident pump power

### 3. Experimental setup and results

The experimental setup is presented on Fig.2. The fiber is longitudinally pumped by a fiber-coupled laser diode with a maximum output power of 60 W at 940 nm. The pump was injected inside the crystal fiber thanks to two doublets and was guided inside the crystal fiber by total internal reflection.

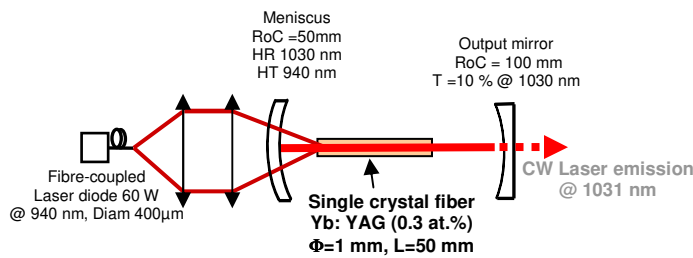


Fig 2. Experimental setup: total length of the cavity is 18 mm

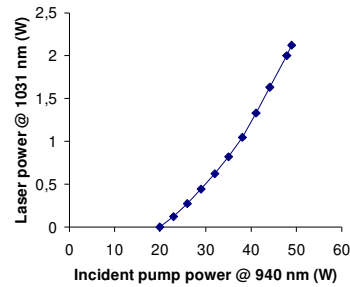


Fig.3. CW laser efficiency

Laser emission was achieved with a two mirrors cavity. The output mirror had a transmission of 10 % at 1031 nm and a 100 mm radius of curvature. We achieved laser emission at 1031 nm with a threshold around 20 W of incident pump power, as predicted by the simulation. The laser efficiency is plotted on Fig. 3. We achieved a maximum output power of 2.2 W with a M<sup>2</sup> quality factor of 2.8, for an incident pump power of 50 W at room temperature and with very good stability. The efficiency is believed to be limited by the loss of pump power along the cylinder and by the overlap between the pumped region and the laser mode.

### 4. Conclusion

We have demonstrated the first laser operation to our knowledge with a directly grown single crystal fiber, thanks to a well controlled and optimized growing process. These preliminary results are very encouraging for the development of high power systems. Thus, the micro-pulling down technique is clearly believed to be suitable for massive productions with excellent quality of crystal fibers. In future works, we will study the Q-Switched regime and increase the pump power. We will also work on improving the barrel surface quality and realize a hybrid core-clad system in order to increase the efficiency of our system.

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