# A Cryogenic, End Pumped, Zigzag Slab Laser Suitable For Power Scaling

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**Abstract:** Power scaling in solid-state lasers is limited by thermally induced distortion and birefringence in the laser crystal. It is well known that the thermo-mechanical and thermo-optical properties of YAG improve significantly at cryogenic temperatures, but these advantages remain to be fully exploited in robust, power scalable designs. We report the first cryogenic, conduction cooled, end pumped, zigzag slab Yb:YAG laser capable of repeated temperature cycling.

## 1. Introduction

Thermally induced distortion and birefringence limit the power scaling of solid-state lasers. These effects are caused by the temperature gradients induced by the extraction of heat deposited by the pump in the laser host material. The magnitudes of these effects are determined by the thermo-mechanical and thermo-optical properties of the material. These properties significantly improve at cryogenic temperatures, suggesting the possibility of power scaling by operating the same laser at higher pump powers but at lower temperatures. Thus at 77 K, thermal conductivity increases by a factor of 7 for doping < 1%, temperature dependence of refractive index (dn/dT) decreases by a factor of 10 and the thermal expansion coefficient decreases by a factor of 4 [1].

The predicted improvements in laser performance have been demonstrated in thin Yb:YAG-sapphire disks [2] and rods [3]. Power scaling of these geometries requires the use of complex architectures using multiple thin disks and rods. The thin disk geometries, however, require heavy doping, which reduces the thermal conductivity, and thus reduces some the advantages achievable from operating at low temperatures. End pumped slab lasers with low doping concentration and zigzag propagation in the plane of heat extraction can be optimized for superior thermal handling, allowing efficient cooling while maintain excellent absorption. For practical, stable lasers it is important to use cryogen-free conduction cooling and the laser configuration must be optimized to minimize thermo-mechanical stress while taking full advantage of the improved cryogenic properties. We report on a new design of such an optimized, end pumped, zigzag Yb:YAG slab laser that is cryogenically cooled by conduction, is robust and reliable for repeated cryogenic cycling, and which utilizes the advantages and potential power scaling offered by cryogenic temperatures.

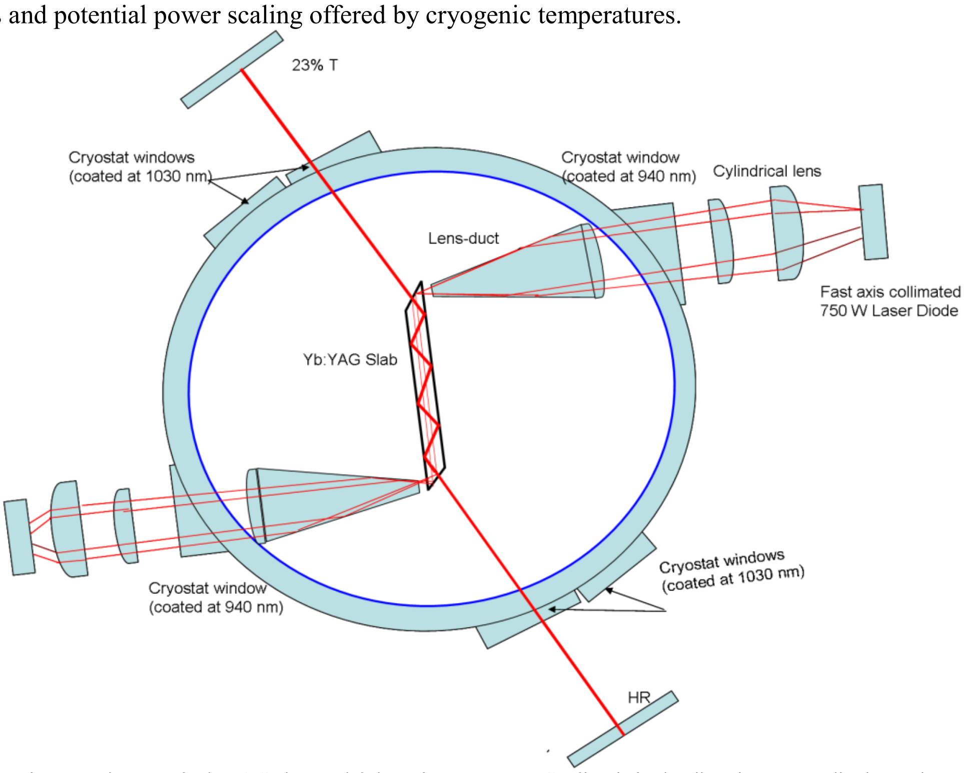


Fig. 1. End pumped Yb:YAG zigzag slab laser in a cryostat. Cooling is in the direction perpendicular to the page.

## 2. Optical design

The optical design of the laser is shown in Fig. 1. It uses a laser crystal design developed for end pumped, single pass, room temperature operation [4]. End pumping is achieved using two fast-axis-collimated 750 W diode stacks, the outputs of which are guided into the slab by lens ducts as shown. This design uses diffusion bonded end-caps of undoped YAG, to ensure a minimum thermal path length to the heat sink from the pumped regions and a true one dimensional heat gradient. The zigzag propagation spatially averages thermal effects and minimizes the impact of thermal distortions and birefringence. End pumping allows for a longer absorption path length, a lower doping concentration and a greater surface area for cooling. Furthermore, the average heat-load density is reduced and the fracture toughness is increased compared to a heavily doped gain medium. At cryogenic temperatures the Yb:YAG changes from a quasi-three level laser to a four level laser system leading to a lower threshold. The pump absorption band at 940 nm remains broad for efficient pumping diode pumping [5].

## 3. Cryogenic conduction cooling

Cryogenic lasers need to be assembled at room temperature but operate at 80-100 K. Hence the key design issue for this type of laser is to control the stresses caused by differential thermal contraction of the materials used in the laser head, while still using materials with high thermal conductivity. To enable cryogenic cycling, the materials in the laser head must never exceed their yield point during the cycle, and different material in contact with each other must be carefully chosen to minimize mechanical strain. Additionally, it is essential that the gain medium is in excellent thermal contact with the heat sink at cryogenic temperatures.

To satisfy these requirements, we have designed and developed a composite Yb:YAG-indium-molybdenum aluminium laser head configuration in which the Al heat sink contracts differentially to make excellent thermal contact with the Mo laser head at cryogenic temperatures, without exceeding the yield stress of the materials within the head and without applying excess stresses to the gain medium.

## 4. Reliable conduction cooling and cycling capability

For initial tests of thermo-mechanically induced optical strain at cryogenic temperatures, we used a test YAG slab, doped with 1% Yb ions with dimensions equal to the final laser slab, but with orthogonal sides. This allowed for a straight-through, Mach-Zehnder interferometric investigation of the optical properties of the slab when cooled. When the mechanical optimization was completed we successfully demonstrated, that our design suffers from no wave-front distortion or stress induced birefringent losses caused by the cryogenic cooling, while maintaining excellent thermal contact. Typical results from this investigation are shown in Fig. 2. To the best of our knowledge it is the first time that this has been achieved in a cryogenic laser gain medium.

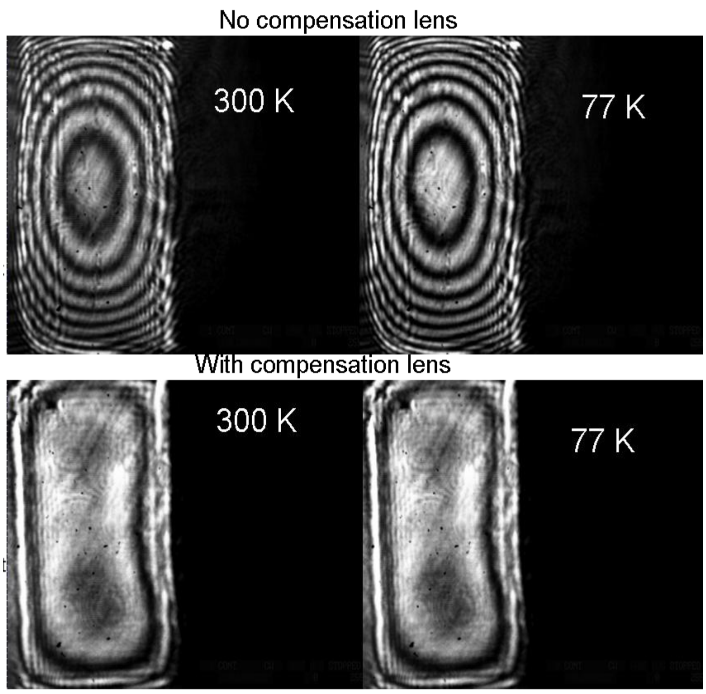


Fig. 2. Mach Zehnder interferogram images showing the wave-front distortion from left to right at room temperature and when cooled to 77 K. The fringes in the upper left interferogram are due to in-built wavefront distortion in the test slab, which could be partially compensated by a simple lens as shown in the lower-left interferogram.

## 5. Preliminary lasing results

Using the zigzag laser slab, initial cw lasing was achieved at 1030 nm with output up to 50 W and with negligible temperature rise in the laser head. We are currently working on significant power scaling and beam quality control of the laser design.

## 6. Conclusion

We have developed a new cryogenic laser design that makes use of zigzag laser slab and conduction cooling, optimized for power scaling. The design has been successfully demonstrated to minimize mechanical stress and wave-front distortion, when cooled to cryogenic temperatures. Initial lasing results confirm the design. The design offers a promising method for generating a robust and reliable high-power solid-state laser with excellent beam quality, and repeated cycling capability. We shall present details of the design and the latest results on the laser performance.

## 7. Acknowledgments

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## 8. References

[1] David.C Brown et. al *"Ultrahigh-Average-Power Diode-Pumped Nd:YAG and Yb:YAG Lasers"*, Journal of Quantum Electronics, IEEE Vol. 33, Issue 5, May 1997, pp. 861-873.

[2] David.C Brown et. al *"Innovative High-Power CW Yb:YAG Cryogenic Lasers"*, SPIE, Proceedings Vol. 33, Issue 5, 20 February 2007

[3] Ripin.D.J et. al *"300-W Cryogenically cooled Yb:YAG Laser",* Journal of Quantum Electronics, IEEE Vol. 41, Issue 10, October 2005 pp.1274-1277.

[4] Gregory. D Godono et. al *"Yb: YAG " Power oscillator with high brightness and linear polarization"* IEEE Volume 26, No. 21, November 2001, pp. 1672-1674

[5]] David.C Brown et. al *"Yb: YAG Absorption at Ambient and Cryogenic Temperature"*, Journal of Selected Topics In Quantum Electronics, IEEE Volume 11, Issue 3, May/June 2005, pp. 604-611.