Cryogenic, Conduction Cooled, End Pumped, Zigzag Slab Laser, Suitable for Power Scaling

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Abstract: Thermo mechanical and thermo optical properties of Yb:YAG improve significantly at cryogenic temperatures. We present the first end pumped, zigzag slab Yb:YAG geometry, which is cryogenically conduction cooled, robust, and power scalable.

1. Introduction

Thermally induced distortion and birefringence due to unavoidable thermal gradients limit the power scaling of solid-state lasers. The magnitudes of these effects are determined by the thermo-mechanical and thermo-optical properties of the material and they reduce significantly at cryogenic temperatures, suggesting a very promising approach for power scaling [1]. The predicted improvements in laser performance have been partially demonstrated in thin Yb:YAG-sapphire disks [2] and rods [3]. However associated with these choices are limitations due to the geometry. Thus rod lasers have limited power scaling due to large radial thermal gradients and disk geometries require heavy doping, which in turn reduces the thermal conductivity and thus reduces some of the advantages achievable from operating at low temperatures.

We have developed an optimized, cryogenic, end pumped, low doping concentration, zigzag Yb:YAG slab. It is conduction cooled from both sides, power scalable, robust and reliable for repeated cryogenic cycling and utilizes the advantages and potential power scaling possible at cryogenic temperatures.

2. End pumped zigzag slab geometry

The end pumped geometry was chosen because it separates pumping and cooling interfaces, allowing long pump absorption path-lengths and thinner slabs to be used, thus providing scalability. This geometry allows for low doping concentration without sacrificing laser efficiency, while maintaining excellent absorption, efficient cooling and the use of zigzag propagation in the plane of heat extraction. Our design is optimized to use cryogenic-free conduction cooling, and minimizes thermo-mechanical stress while taking full advantage of the improved cryogenic properties.

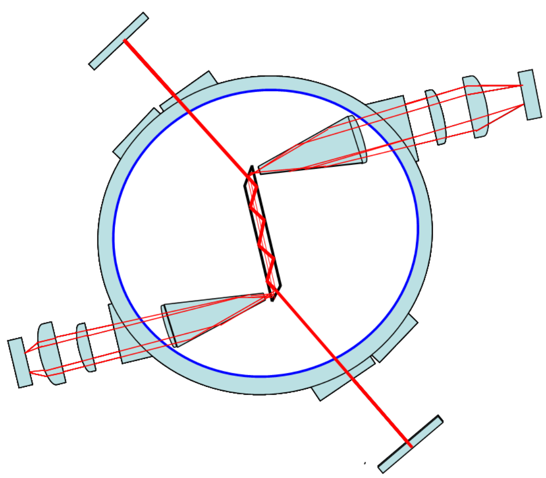

Fig. 1. End pumped Yb:YAG zigzag slab laser in a cryostat. Cooling is in the direction perpendicular to the page.

3. Optical design

The optical design of the laser is shown in Fig. 1. It uses a laser crystal design with undoped end-caps similar to that developed for end pumped operation [4] in a unique laser head designed for cryogenic operation. Uniform pumping from the two fast-axis-collimated 750 W diode stacks is achieved using a lens-duct beam homogenizer. The zigzag propagation spatially averages thermal effects and minimizes the impact of thermal distortions and birefringence. The doping concentration is 1 % Yb ions to maximize the advantages of cryogenic operation.

4. 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 stress and strain caused from cooling. Additionally, it is essential that the gain medium is in excellent thermal contact with the heat sink, without adding net stress to the slab 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 large 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.

5. Reliable conduction cooling and cycling capability

Pumping and lasing optimization tests have been completed incorporating a Mach-Zehnder interferometer to investigate the optical properties of the slab at room temperature and when cooled. The results demonstrate that our design does not suffer from wave-front distortion or stress induced birefringence losses caused by the cryogenic cooling, while maintaining excellent thermal contact. To the best of our knowledge it is the first time that this has been achieved in a cryogenic laser gain medium. The good thermal contact and ability to dissipate heat was demonstrated when the slab was heavily pumped with up to 300 W absorbed power while showing no sign of wave-front distortion at 80 K and was very favorably compared with distortions suffered at room temperature at same power level. Typical results from this investigation are shown in Fig. 2.

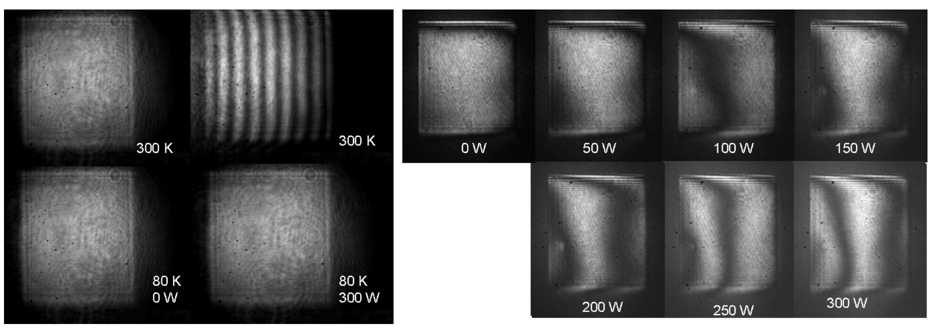

Fig. 2. Mach Zehnder interferograms showing: a) No wave-front distortions: at room temperature, when cooled to 80 K and when heavily pumped at 80 K. b) Wave-front distortions seen only at room temperature as function of absorbed pump power. No such pump power dependent distortions were observed at 80K.

7. Conclusion

We have developed a new cryogenic laser design which uses a zigzag end pumped slab laser and which is conduction cooled from both sides, while optimized for power scaling. The design is well suited for power scaling. It has been successfully demonstrated to minimize mechanical stress and wave-front distortion, when cooled to cryogenic temperatures. Initial lasing results confirm the design. We shall present details of the design and the latest results on the laser performance.

8. Acknowledgments

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8. References

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