

4. Discussion and conclusions

The high slope efficiency achieved with this laser is attributed to a number of factors. To maximize the slope efficiency, the overlap efficiency between the laser and pump beams must be very high and the extraction efficiency must also have a very large value. These two factors, combined with operation at 77 K to minimize thermal effects and maximize the gain, and the fact that Yb:YAG does not exhibit any efficiency robbing parasitic effects such as up-conversion, concentration-quenching, or excited-state absorption, are primarily responsible for the results presented here. Because slope efficiency is defined with respect to the absorbed pump power, the less than ideal absorption of about 62% at 946 nm plays no role. Future iterations of the laser described here will include improving the pump absorption by increasing the optical density of the Yb:YAG crystal and/or multi-passing the pump beam, and by replacing the 946 nm Nd:YAG laser with a high brightness diode laser pump source.

By using an X-resonator operated in the near-confocal regime, a small laser mode diameter is achieved in the Yb:YAG laser crystal, well-matched to the 28-39 μm $1/e^2$ pump diameter. Mode matching between the two beams is achieved in practice by iterating the distance between the center of the curved HR 10 cm radius mirrors and the center of the Yb:YAG crystal. If both the pump and laser beams are completely overlapping spatially (in a 3-D sense), and the laser mode diameter is greater than or equal to the pump beam everywhere in the laser crystal, nearly unity overlap efficiency results. This circumstance is largely attributable to the closeness of the pump and laser wavelengths and to the use of a diffraction-limited pump source rather than a multimode diode source with a large M^2 .

Calculation shows that inside the Yb:YAG laser crystal and with a 50% transmission outcoupler, the ratio of the peak central intensity of the added forward and backward traveling resonator extraction beams to the saturation intensity is about a factor of 35. This high ratio, which results from the use of a nearly-confocal Z-resonator, when combined with the high small-signal gain, results in near-unity Gaussian beam extraction efficiency [9].

It is clear from the results presented here that the demonstration of heat-fraction-limited, diffraction-limited lasers depends upon a number of important factors, amongst them operation at 77 K to maximize the small-signal gain and eliminate any thermal aberrations, the use of a diffraction-limited pump source whose wavelength is not far different from the laser wavelength to produce a near-unity overlap efficiency, and a small laser mode diameter in the laser crystal to produce a large ratio of laser intensity to saturation intensity. It is hoped that the guidance provided by these principles may lead to other similar demonstrations in the near future.

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