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High Power Diode Pumped Solid State Laser Development at Lawrence Livermore National Laboratory

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B. Dane, C. Hamilton, and C. Ebbers

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DISCLAIMER

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Abstract

We review recent developments in high powered diode pumped solid state lasers at Lawrence Livermore National Laboratory. Over the past year we have made continued improvements to semiconductor pump array technology which includes the development of higher average power and lower cost pump modules. We report the performance of high power AlGaAs, InGaAs, and AlGaInP arrays. We also report on improvements to our integrated micro-optics designs in conjunction with lensing duct technology which gives rise to very high performance end pumping designs for solid state lasers which have major advantages which we detail. Substantial progress on beam quality improvements to near the diffraction limit at very high power have also been made and will be reported. We also will discuss recent experiments on high power non-linear materials for q-switches, harmonic converters, and parametric oscillators. Advances in diode pumped devices at LLNL which include tunable Cr:$LiSrAlF_6$, mid-IR Er:YAG, holmium based lasers and other developments will also be outlined. Concepts for delivering up to 3 kilowatts of average power from a DPSSL oscillator will be described.

Diode pumping of solid state lasers is being pursued with greater and greater interest as progress continues to be made world wide on all aspects of device technology. At LLNL we have continued to develop very high power diode pumped solid state lasers for applications in industry, defense, energy, and remote sensing. Our strategy includes the following components: a) the development of high average power and low cost diode pump arrays by emphasizing performance improvements in the average power in the arrays as a method to increasing the figure of merit which is dollars per average watt, b) placing particular emphasis upon the interplay between diode technology and insulating crystal technology and developing the two in unison rather than separately, this interplay leading to unique architectural solutions to prominent laser device design problems, c) improving the performance of non-linear materials whose component performance defines the ability of all solid state systems to diversify their operating regimes, and d) continuing the high leverage search for new crystalline host materials.

Semiconductor laser developments

The microchannel cooling technology which has been pioneered at LLNL for the packaging of high power semiconductor laser arrays is not described here as it has appeared already in many publications. The major advances which have occurred recently at LLNL are based upon the fact that the semiconductor material grown at

LLNL is extremely low loss (1/cm-1), permitting the use of longer semiconductor cavity lengths (of order of millimeters) thus creating a larger thermal footprint on the cooling submount, and the recognition that facet damage improvements would allow for the extraction of higher powers from diode bars. Figure 1 illustrates the power which can be extracted from one of our microchannel cooled diode packages as a function of diode laser bar cavity length. The thermal cooling power increases approximately linearly with the cavity length and therefore the real footprint of the diode bar as is shown in the figure. The figure also shows the maximum extractable power as a function of cavity length as a function of two loss figures, $1/cm^{-1}$ and $5/cm^{-1}$. The untreated AlGaAs facet damage limit of nominally 10-15 mW/micron of aperture is also shown. Clearly raising this performance value by significant factors are important to increasing the overall average power which can be supported by the extractable power and cooling performance. Facet preparation, modeled along the important results achieved at IBM Zurich and elsewhere, now implemented at LLNL, clearly shows that achieving from 500 watts to one kilowatt or more of average power from our standard microchannel cooled chip is achievable. Figure 2 shows recent results in which 96 watts per linear centimeter of bar output are achieved (power supply limited) without facet treatment and only using the advantage of long and low loss bars. While we must still quantify the extent of I2R heating in our high power bar packaging configuration and its effect upon efficiency at high powers and its subsequent effects upon lifetime, it is clear that major advances in the performance of average power microchannel cooled chips will still be achieved.

Figure 3 illustrates recent results from high power AlGaInP material in cw performance using our packaging methods. The high power and efficiency achieved for this material is an exciting development in that this material can be very effective in pumping tunable solid state lasers which are Cr^{+3} based in either $LiSrAlF_6$, $LiCaAlF_6$, or alexandrite. All solid state systems approaching 10% efficiency which are tunable in the near IR are now possible.

Diode pumped solid state laser architectures

Diode laser arrays are capable of delivering not only reliable and cheap energy to solid state laser host materials but also in formats which cannot be achieved with flash lamp pumping. A significant development this past year was made in the area of end pumping which illustrates this concept.

Figure 4 shows an integrated microchannel cooled diode array with a microlens package. These microlenses are used to collimate the radiation emerging along the fast axis of the diode axis from a divergence of one radian to less than ten milliradians. A lensing duct is then placed at the output of the two dimensional collimated array to condense the light field further along both axes perpendicular to the axis of propagation. Using this approach over 75 kW/cm^2 of optical fluence can be delivered from diode arrays to the end of a solid state laser rod. Our calculations indicate that a 20 cm long Yb:YAG rod pumped in this manner should be a free running or cw device capable of operating at 3 kilowatts of average power at one micron. A major advantage of this very simple and high power device is that the diode radiation, when used in this end pumped geometry, is presented with many optical absorbances of the active optical ion. This gives rise to a very intense and broad absorption feature which in turn allows for greatly relaxed temperature control of the laser diodes. The very high fluences used in this pumping geometry is also useful for achieving high gains in materials with small cross sections for stimulated emission.

High average power non-linear materials

The development of high average power nonlinear materials for q-switches, optical parametric oscillators, and harmonic converters is critical to expanding the wavelength range for solid state lasers. We have embarked on a program to develop and evaluate new nonlinear materials, to develop architectures which minimize intersystem cavity losses and which minimize thermal effects.

We recently reported an all solid state diode pumped oscillator which operated at 275 watts of optical output at one micron using a thermally compensated z axis lithium niobate Pockels cell. We also have demonstrated athermal operation of a finite birefringence Q-switch in KTP and have developed excellent compensation of thermal birefringence in other architectures at several kW/cm^2 loading. New pyroelectric and photorefractive depolarization mechanisms have been observed in finite birefringence lithium niobate Q-switches and will be reported. We have also generated 100 watts of frequency doubled light from the output of a 200 watt diode pumped slab Nd:YAG oscillator. The harmonic doubler was a thin slab of KTP.

We have also constructed InGaAs pumped Er:YAG devices which are tunable over an eight cm-1 range near 2.935 microns, diode pumped $LiSrAlF_6$ devices, diode pumped Tm:YAG, as well as joule per pulse diode pumped amplifiers which are used in regenerative architectures with phase conjugate cells for beam clean up. These will be described briefly. We will report on the recent progress made in these experiments as well as recent studies on optical parametric oscillators at high average power.

Acknowledgment

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

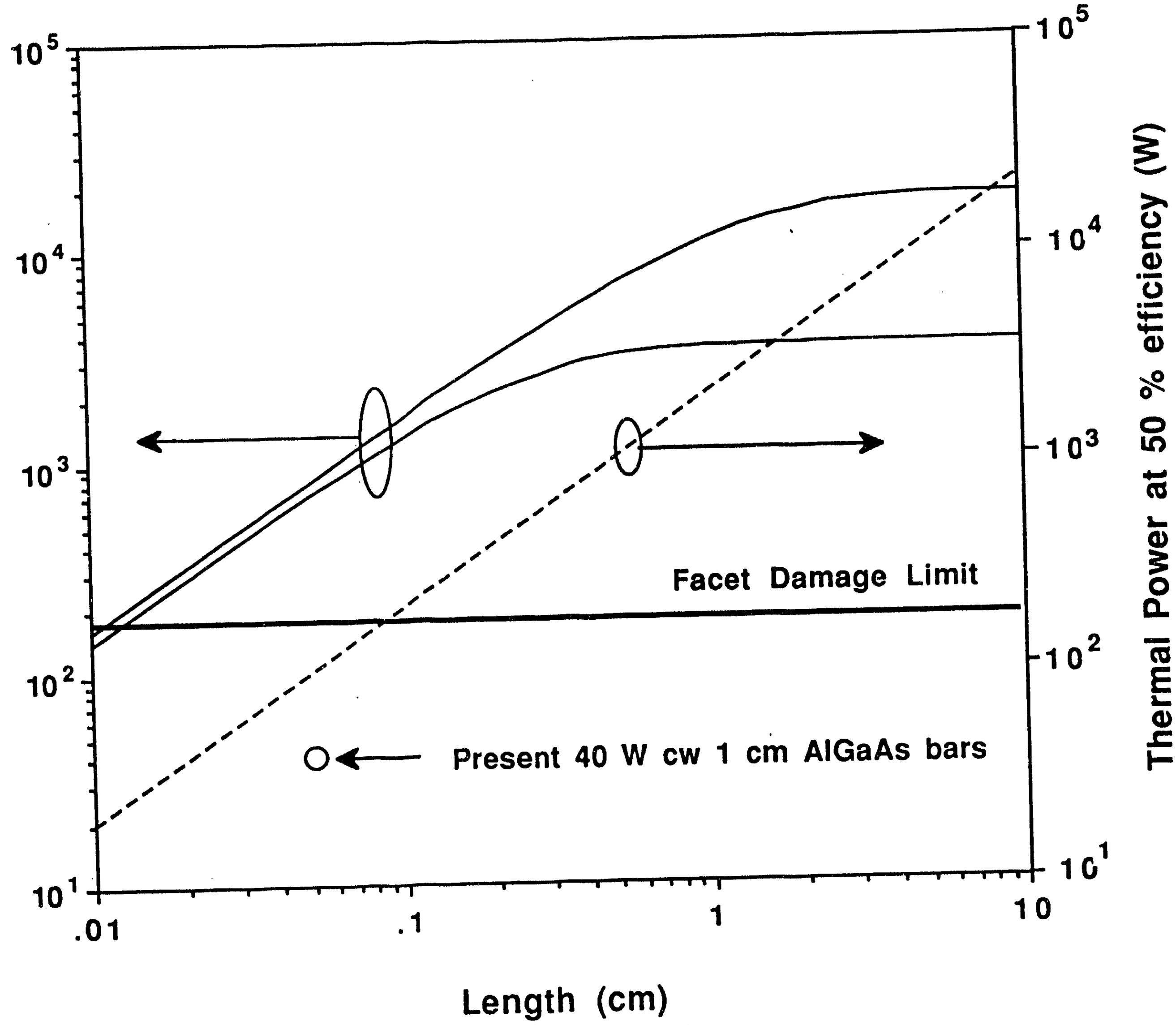
Thermal Power at 50 % efficiency (W)
Facet Damage Limit
Present 40 W cw 1 cm AlGaAs bars
Length (cm)
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Fig (1)

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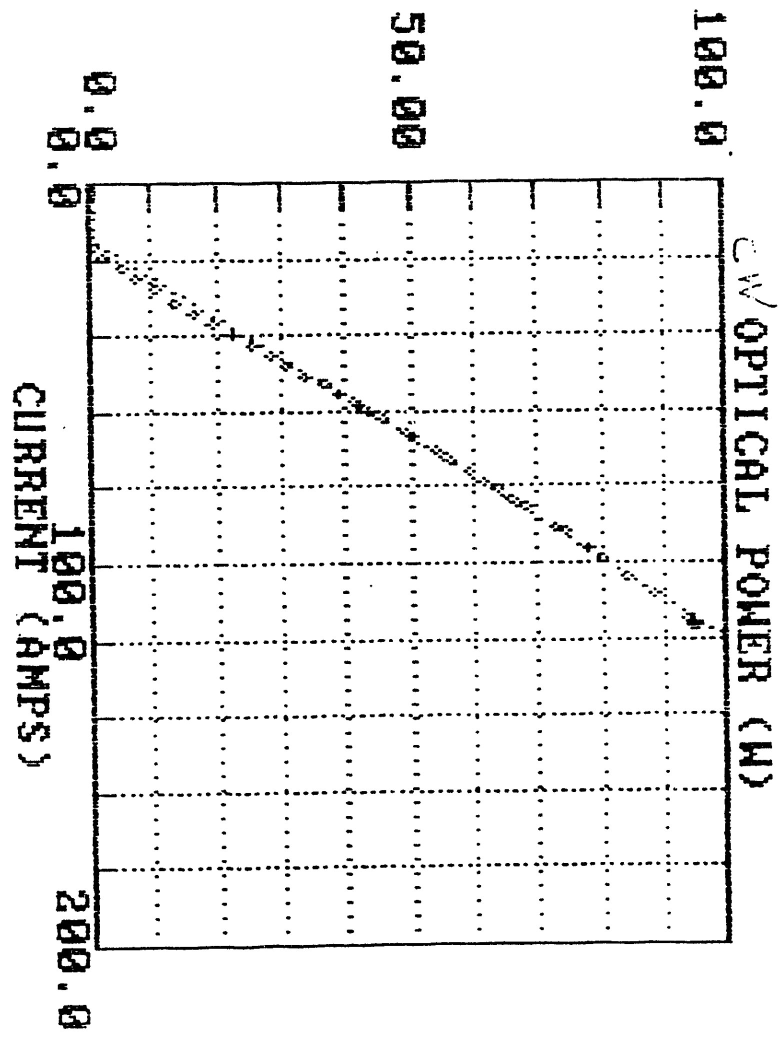

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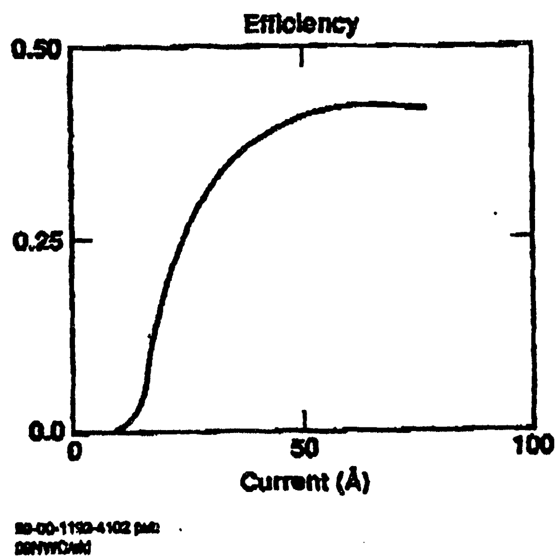
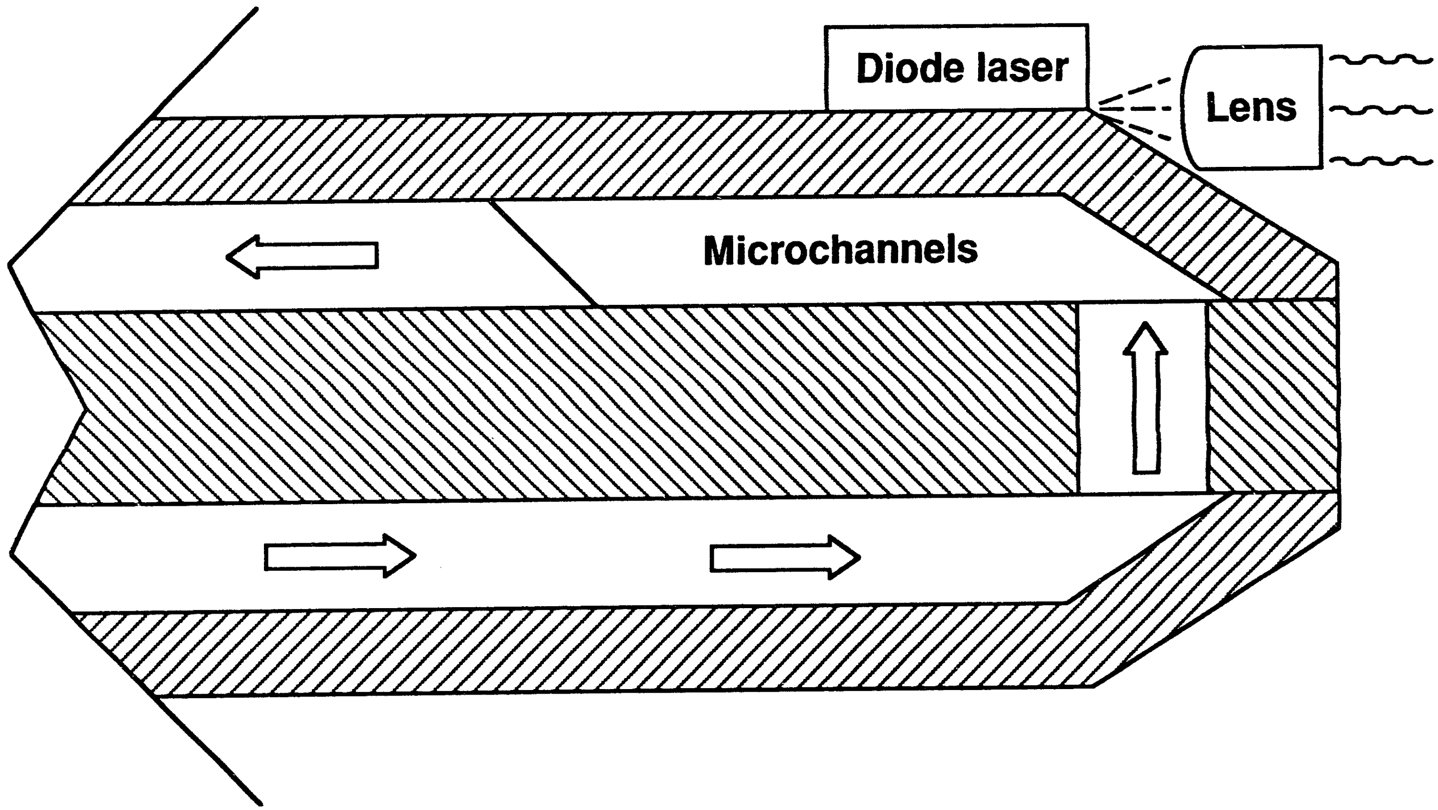
Figure 3. The power conversion efficiency versus current curve of a 1 cm wide AlGaInP diode-laser array under cw operation.

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