The University of Tokyo COE21 Program
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「極限量子系とその対称性」

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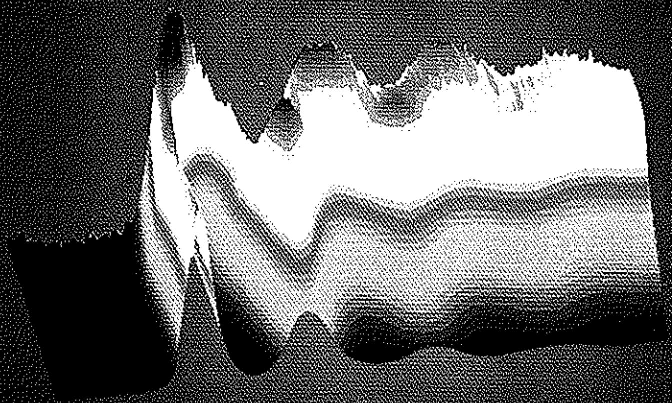
International Workshop 2005

DIMA

Frontiers of Laser and Optical Sciences

Abstracts



October 1 (Sat.) - 2 (Sun.), 2005
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Limits of the power scaling of lasers

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0. Preamble. We discuss the output power limitations of the two possible architectures for high power lasers: the coherent combining fiber laser and the size scaling of the disk lasers.

1. Passive coherent combining of single-mode lasers. The common cavity with single-mode coupling (Fig.1) provides both spectral refinement of the generated light and the scaling of the output power [1-6].

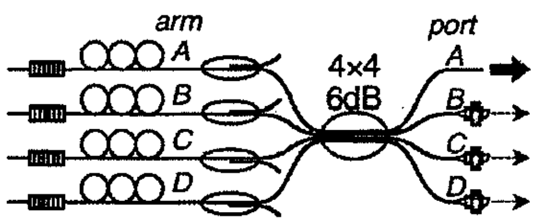

Fig. 1. Example of laser combining by [5].

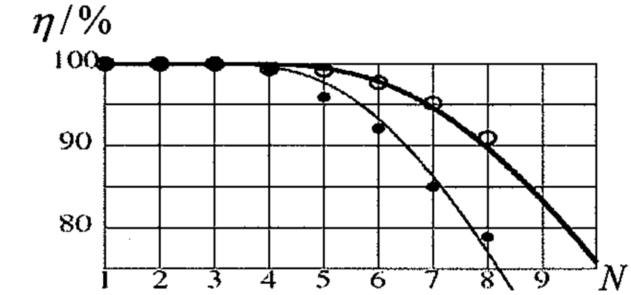

Fig.2. Efficiency of combining: simulations [5] (dots, circles) and the estimate $\eta=\eta(N)$ [8].

The detailed analysis may imply a complicated simulations [5,7]. Here we suggest the quick analytical estimate. Let each laser operate around wavenumber K, with bandwidth ΔK. Then the nth added laser chooses some frequencies of operation among the frequencies of operation of the system of n-1 lasers. If we have only one laser (N = 1), we can expect the generation at the set of frequencies, and have in the order of $\Delta K L$ spectral lines at the output. Let us add one additional laser. Let the output coupler discriminate modes with the high losses, let the modes which have coupling losses less than (1-η) be below threshold. Then, approximately, the (1-η)th part of the signal power goes to other output ports and presumably cannot be used for the single-mode operation. This portion of power is lost, and η can be interpreted as the efficiency of combining. This leads to the estimate [8] of maximal number N of lasers which can be combined at the given efficiency η:

$$N-1=\frac{\ln(\Delta K\, L)}{\ln\left(\pi/\sqrt{2(1-\eta)}\right)}$$

This formula can be inverted in order to estimate the efficiency η of combing of given number N of lasers:

$$\eta=1-\frac{\pi^2}{2}\exp\left(-2\frac{\ln(\Delta K\, L)}{N-1}\right)$$

Such estimate agrees with the numerical simulations by Shirakawa [5] (Fig.2). In the typical case, up to 8 lasers can be combined in such a way.

2. Surface losses limit the power scaling of disc laser. The thin disc geometry (Fig.3) is used in broad range of output powers. Increasing the size of the disc is supposed to allow the high output power. We consider limits of such a power scaling in [9].

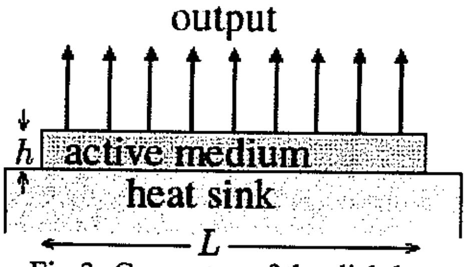

Fig.3. Geometry of the disk laser.

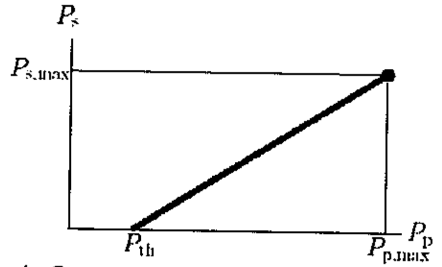

Fig.4. Output power versus the pump power.

Let β be the surface scattering loss. The round-trip gain $g = 2\,G\,h$ should be larger than β. The scaling of the maximal size L increases the amplified spontaneous emission of the disk and forces to reduce the gain G and increase the thickness h. Over a certain size, the laser cannot be pumped well above threshold without overheating. This determines the limit of the power scaling of the disk lasers [9], whenever the single-mode output is required or not.

Let Q be the saturation intensity, and $R = \min\begin{cases} 3R_{\rm T}T/\gamma \\ 2k\,\Delta T/\gamma \end{cases}$, where $R_{\rm T}$ is the thermal shock parameter, ΔT is maximal variation of temperature allowed for the active medium, γ is the heat generation coefficient, and k is thermal conductivity. Let $\eta_0 = \omega_s/\omega_p$ be quantum limit of the efficiency. These parameters allow to estimate the maximal power (Fig.4) of such a laser: $P_{s,\max} = \dfrac{27R^2\eta_0}{64e^2Q\beta^3}$. This is a key parameter in the choice of materials for the high power disk laser. It strongly depends on the surface scattering losses. Our estimate is universal for vsrious kinds of the active media.

3. Conclusion. We suggest the fundamental limits of the power scaling for the laser combining with passive synchronization of lasers and for the scaling of size of the disc lasers. The following power scaling of can be achieved by the active synchronization of lasers: the phase of each laser should be locked to the reference laser as a frequency standard. The development of the phase-locked powerful lasers becomes one important branch of the laser science.

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[9] D. Kouznetsov, J.-F. Bisson, J. Dong, and K. Ueda. Surface losses limit the power scaling of disc laser. – JOSA **B,** under consideration. http://www.ils.uec.ac.jp/~dima/disc.pdf