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Scaling Laws of Deformation of Active Mirror Lasers

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A thin disk element of an active mirror laser[1-6] will bend due to the heat sink and the resulting temperature gradient that develops across the active element. This will cause thermal lensing beam distortion, thereby reducing the beam quality. We estimate the curvature of a thin slab to the relevant thermo-mechanical properties of the active material, the heat load and its thickness. Our estimate the trend of deformation as a function of the operating temperature, thickness and heat load. Such estimate is very difficult to get when using numerical solutions.

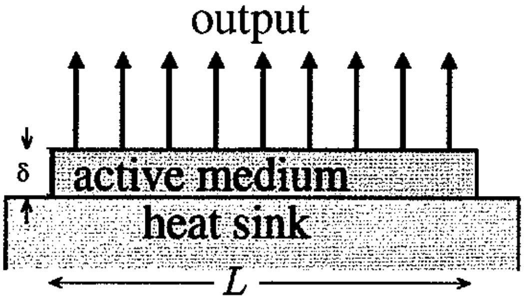

Fig. 1 Schematic diagram of the thin-disk laser.

An illustration of the thin-disk laser is shown in Fig. 1. The back surface is used as a cooling interface and one reflector of the resonator. The large cooling surface relative to the heated volume enables efficient cooling. The active element is assumed to bend freely; this is the case if the heat sink is soft; direct water cooling is one example. Moreover, since the heat is preferentially drained from the back surface, the temperature gradient is parallel to the optical axis of the resonator, so that thermal lensing due to transverse temperature gradient is minimized. However, lensing effect occurs because of the thermo-mechanical deformations, which arise from the temperature gradient and the resulting differential thermal expansion of the material, Fig. 2. These deformations are stronger in thinner materials because they are more flexible than the similar thicker material.[7]

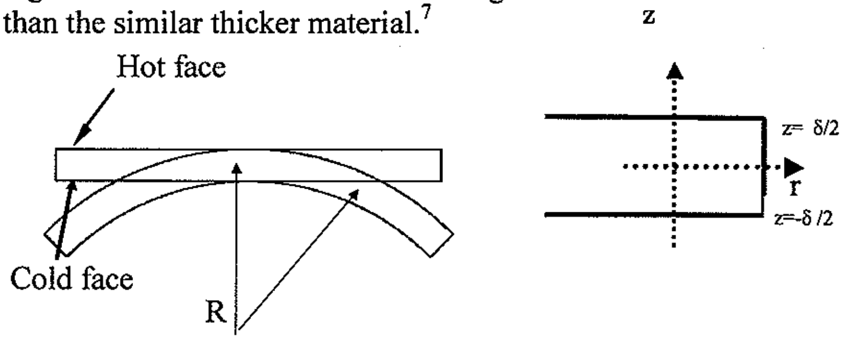

Fig. 2 Left: under inhomogeneous temperature field, the active material bends with radius R. Right: the origin of coordinates, z=0, is taken at the middle plan of the slab.

The estimate of the deformation involves the following steps:

1) estimate of the temperature field by using the heat diffusion equation with appropriate boundary conditions. A 1D heat flow is assumed;

2) estimate of the stress distribution[7] , σ : $\sigma(z)=\frac{E\alpha}{(1-\nu)}(T(z)-\frac{1}{\delta}\int_{-\delta/2}^{\delta/2}T(z')dz')$ where T is the temperature distribution, δ is the thickness of the active element, E is the Young Modulus, α is the thermal expansion coefficient, ν is the Poisson coefficient;

3) estimate the resulting torque M: $M=\int_{-\delta/2}^{\delta/2}\sigma_x(z')z'dz'=\frac{\alpha E}{1-\nu}\frac{U\delta^4}{24}$ where U is the heating density [W/m^3], assumed uniform;

4) calculate the curvature using[7] $M_c=\frac{1}{R}\frac{E\delta^3}{12(1-\nu)}$. This gives: $\frac{1}{R}=\frac{\alpha U\delta}{2K}$, where K is the thermal conductivity.

The deformation is proportional to the deposited heating power per unit area, regardless the material thickness. It is proportional to the ratioα/K. Within our model, the deformation does not depend on the Young modulus E nor on the Poisson coefficient, ν. The strong temperature dependence of the ratio α/K for crystalline materials suggests that operating the laser at cryogenic temperature may significantly reduce thermal deformation. The evolution of K and α for YAG are shown in Fig. 3.[8] The advantages of using composite materials made of an undoped and doped layers bonded together will also be discussed.

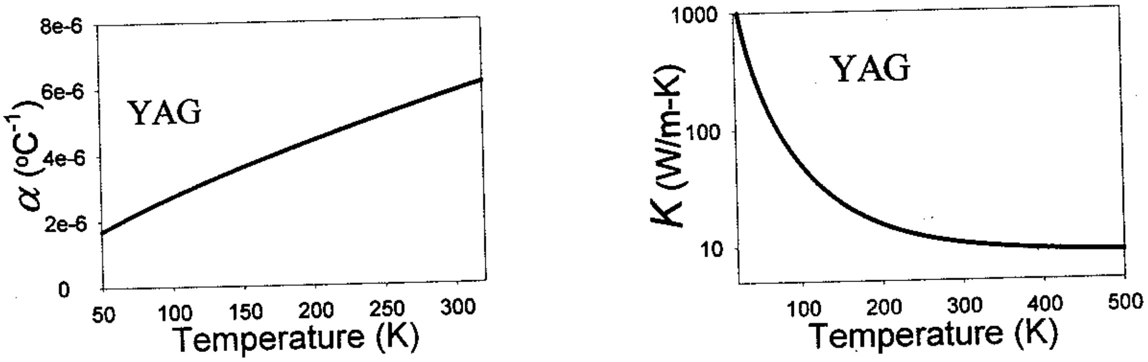

Fig. 3 Thermal expansion and thermal conductivity as a function of temperature for $Y_3Al_{12}O_5$.

References

[1] A. Giesen, H. Hügel, A. Voss, K. Wittig, U. Brauch and H. Opower: Appl. Phys. B **58** (1994) 365.
[2] K. Contag, M. Karszewski, C. Stewen, A. Giesen and H. Hügel: Quantum Electron. **29(8)** (1999) 697.
[3] K. Contag, S. Erhard, M. Karszewski, M. Larionov, D. Muller, C. Stewen, A. Giesen and I. Johannsen: Tech. Dig. Conf. on Lasers and Electro-Optics (CLEO 2000), San Francisco 2000 May, Postconference Edition. TOPS Vol. 39, p. 198.
[4] D.Kouznetsov, J.-F.Bisson, J.Dong, K.Ueda, *Surface losses limit the power scaling of disc laser*. JOSA B, 2005, under consideration. Cf. http:// www.ils.uec.ac.jp/~dima/disc.ps.gz.
[5] A. J. Kemp, G. J. Valentine, D. Burns, Prog. Quantum Electron., **28** (2004), p.305.
[6] S. B. Ubizskii, A. O. Matkovskii, S. S. Melnyk, I. M. Syvorotka, V. Muller, V. Peters, K. Petermann, A. Beyertt, A. Giesen, Phys. Stat. Solidi A- Appl. Research, **201 (4)** (2004), p. 791.
[7] S. Timoshenko and J. N. Goodier, Theory of elasticity, McGraw-Hill 2nd Ed., 1951.
[8] Brown, IEEE J. Q. Electron. 33(5) (1997) 861.