L.5: Diode-end-pumped Nd:YVO$_4$ laser with different cooling geometries

Cylindrical rod geometries are very common and widely utilized form of cross section in laser gain medium, since one can easily achieve cylindrically symmetric pumped volume. Also the desired TEM$_{00}$ laser mode exhibits radial and azimuthal symmetry. For isotropic laser crystal such as Nd:YAG, if the cooling is provided over the circumference of the rod either by means of conduction or by flowing water, then the circumference temperature would be close to that of heat sink or coolant temperature. The heat flow and resultant thermal gradients would be radial. When the material exhibits positive index of refraction as function of temperature, then the radial gradient in the index of refraction as a function of radius, results in a spherical thermal lens. In contrast, square cross section is the preferred geometry for crystals possessing strong anisotropy like Nd:YVO$_4$/ Nd:YLF. In such material it is difficult to produce a radially symmetric thermal lens. The effect of cooling geometry on laser performance using 'c'-plane cooling, 'a'-plane cooling and all-side cooling, in Nd:YVO$_4$ crystal operating under end-pumped configuration have been studied experimentally. The schematic of the crystal orientation and cooling geometries are shown in Fig.L.5.1.

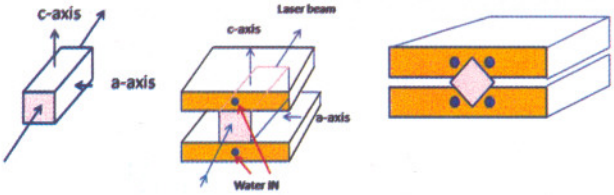

Fig.L.5.1. Orientation of the crystal and its cooling geometry (a): c-axis cooling for a-axis cooling rotate crystal by 90 deg (b) and all-side cooling (c).

In all-side cooling, the crystal is wrapped with indium foil before clamping between a set of symmetric water circulated copper blocks over entire circumference of the crystal, whereas in single plane cooling the crystal is clamped between two opposing water circulated copper blocks. There are key differences between Nd:YVO$_4$ and Nd:YAG. Primarily the later is a isotropic crystal while Nd:YVO$_4$ is strongly anisotropic. Therefore for a given pump source it is relatively easy to generate spherical thermal lens in Nd:YAG, however it is difficult to produce spherical thermal lens in an anisotropic material such as Nd:YLF or Nd:YVO$_4$. Nd:YVO$_4$ particularly have the optical, and thermo-mechanical characteristics that are greatly different along the ordinary and extraordinary crystallographic axes, thus the thermally induced lens is elliptical. In such a situation it is better to cool along the single plane where the lensing is stronger, thereby to achieve thermally induced lens close to cylindrical in nature. This may appreciably improve the laser performance. Thermal lensing mainly depends on temperature dependent refractive index variation (dn/dT) and thermal expansion coefficient (α). For Nd :YVO$_4$, α value in the direction parallel to the a-axis is about 2.5 times smaller than that to the c-axis. The variation of dn/dT is different by a factor 2.8 along the c and a axis. Additionally there is more than 10% difference between the indices of refraction for two crystallographic axes. Considering these factors for the given thermal gradients it is expected stronger lensing behaviour along c- axis than along a-axis.

We have used rectangular Nd:YVO$_4$ crystal doped with 0.3 at.% Nd and the dimensions of the crystal are 3x3x10 mm^3. The crystal was wrapped with Indium foil of 100 µm thickness for better thermal contact and placed inside the copper heat sink, which was cooled by circulating water. The pump source was 35W fiber coupled laser diode at wavelength of 808 nm at temperature of 25C. The pump beam was collimated and focused by two plano-convex lenses 25 mm and 50 mm on the Nd:YVO$_4$ crystal. The focused spot size inside the gain medium was estimated to be 400 µm. The cavity rear mirror was plane HR-coated at 1064 nm and HT at 808 nm. The output coupler was 80% reflectivity at 1064 nm. The cavity length was 130 mm.

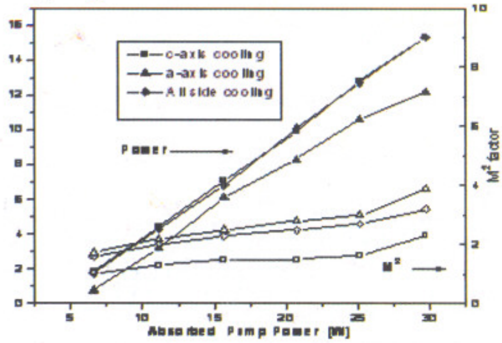

Fig.L.5.2. Plot shows output power and beam quality factor M^2 as a function of absorbed pump power.

The laser was operated under CW operation. The output power and beam quality factor M^2 versus absorbed pump power was recorded as shown in Fig.L.5.2. The laser output in the case of all-side cooling and c-plane cooling was almost the same and increases linear with pump power. Whereas the maximum laser power for a-plane cooling was 12 W with a saturation trend due to strong thermal lensing along the c-axis. Further, the beam quality varies from 1.07 to 2.3 for the c-plane cooling. In contrast, the beam quality factor for all-side cooling and a-axis cooling was ranging from 1.6 to 3.3 and 1.7 to 3.9, respectively. Further, the c-plane cooled laser cavity was operated under AO Q-switching mode and found good RF hold-off capacity and enhanced marking depth. This may be attributed to the good beam quality of the laser beam.

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