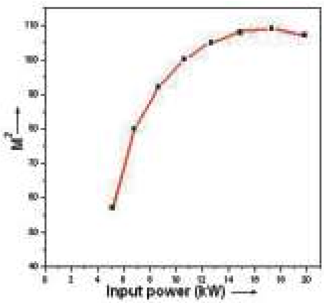

Fig.L.6.3: M^2 value as a function of input pump

Contributed by:
B. N. Upadhyaya (bnand @ cat.ernet.in) and S. M. Oak

L.7 : Development and characterization of highly efficient diode-side-pumped cw Nd:YAG laser

Diode-pumping of solid-state lasers offers several advantages such as high optical-to-optical efficiency, long lifetime of laser diodes, and the realization of compact laser system over conventional flash / arc lamp-pumped systems. In order to achieve higher overall efficiency of the system, the pumping efficiency of the pump cavity and pumping uniformity over the rod cross-section is very important. The requirement of better pumping uniformity plays a dual role in providing uniform thermal load in the gain medium and better extraction of the available laser power in the upper laser level for the given resonator geometry. Keeping the above requirement in mind, Solid State Laser Division of RRCAT has developed a highly efficient copper coated optical pump cavity for continuous wave (cw) operation of high power Nd:YAG laser generating 375 W of output power for a diode pump power of 750 W. This corresponds to an optical-to-optical efficiency of 50% and the electrical-to-optical efficiency of 26%. These efficiencies are the highest reported to the best of our knowledge using 4 mm Φ x 100 mm Nd:YAG rod.

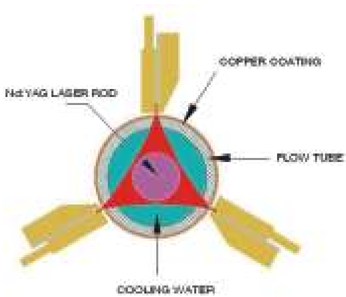

Fig.L.7.1: Schematic of a threefold symmetric pump configuration

The pump head geometry was made up of copper-coated flow tube with three windows of < 1 mm width. Windows are located along the length of the tube and they are at 120 degrees with respect to each other as shown in Fig.L.7.1. Pump light is coupled to the active medium through these windows. The tube is of internal diameter of 8 mm and outer diameter of 10 mm. In the absence of such reflective coatings, the pump beam travels only once through the gain medium. Depending upon the rod size and doping concentration, the absorption of the pump beam varies. Hence, the rest of unabsorbed pump beam is lost, accounting for inefficient coupling of pump beam to the active medium. The pump sources were configured as horizontal stacks of pump diodes, with each stack containing six numbers of 40 W diodes as shown in Fig.L.7.2. The coolant temperature was maintained at 19°C, for both active medium and pump diodes. At this temperature, the central wavelength of the diode modules is about 805.4 nm at the maximum driving current. Although the centre wavelength deviates from the absorption peak of the Nd:YAG laser medium (808.5nm), the output power is maximum due to wing-pumping method. In this method, peak diode emission wavelength is set near the edges of the peak absorption line of Nd:YAG to take advantage of better pumping uniformity over the cross-section of the laser rod.

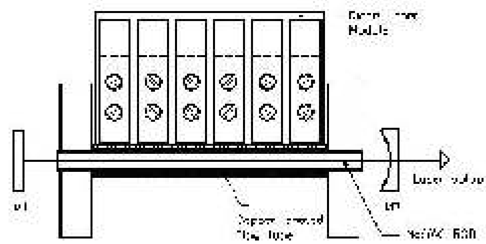

Fig.L.7.2 : Side view of the laser pump head showing only one diode laser module for the sake of clarity and plano-concave resonator for multimode operation

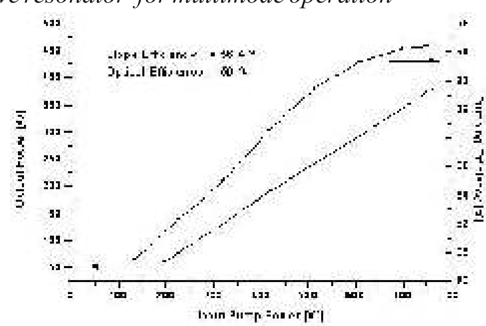

Fig.L.7.3 : Characteristics of the output power and pumping efficiency versus input pump power

The Fresnel loss due to coupling of diode light through flow tube was minimized by using p-polarized diode light. In order to find out the effectiveness of the pumping scheme with polarized pump beam, the pumping efficiency

(η_p) was measured by the "pump power leakage" technique. The pumping efficiency is defined as the ratio of the power absorbed by the rod to the total diode pump power. The pump power leakage from the window of the coated flow tube with 400-µm core fiber, which was directly coupled to the power meter with a filter to block the rod's fluorescence, was measured. The pumping efficiency, as the ratio between the leakage powers from the Nd:YAG rod and that of the reference rod, was estimated and it is approximately ($1-\eta_p$) as shown in Fig.L.7.3. The pump-power-dependent η_p varies from 79% to 94%. The high efficiency of the system can be attributed to wing-pumping method resulting in uniform pump light distribution and better pumping efficiency due to p-polarized pump beams. The resonator was a close-coupled geometry with plane mirror as highly reflecting mirror and 5 m radius of curvature 85 % reflectivity as output coupler mirror. The length of the resonator was 135 mm. The beam quality factor (M^2) was measured to be < 70. Fig.L.7.4 shows the photograph of the system in operation.

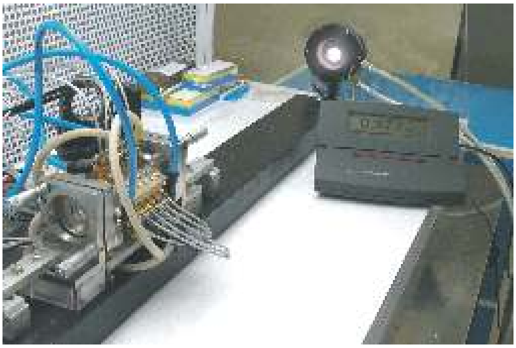

Fig. L.7.4: Photograph of the system in operation

Contributed by :
K. Ranganathan (ranga@cat.ernet.in), R. Sundar, and S. M. Oak

L. 8 : Development of a sealed-off copper bromide laser

Copper bromide (CuBr) laser is a low temperature variation of copper vapour laser (CVL). In a CuBr laser, copper atoms (lasing medium) are generated in a discharge by dissociation of CuBr molecules. Sealed-off CuBr laser has several advantages over elemental CVL. The sealed-off system eliminates the need of gas and vacuum handling system for the operation of the laser. Operating temperature of the laser tube is around 550 ^{0}C as against 1500 ^{0}C for elemental CVL. Thus, the high temperature problems associated with the laser head are not very severe. The warm up time of the laser system is reduced from around 60-90 minutes (for elemental CVL) to around 10 minutes. The discharge in CuBr laser tends to give better beam quality and higher wall plug efficiency as compared to elemental CVL. Considering these advantages, development of sealed-off CuBr laser was taken up in Laser Systems Engineering Division of RRCAT. A sealed-off CuBr laser delivering 4 W average output power has been developed

Schematic diagram of the laser discharge tube is shown in Fig.L.8.1. It is of fused silica and has 37 mm inner diameter, and the total length of the tube, including the extended window region, is 115 cm. There are five side arms on the discharge tube. The outer most side arm pair is used as electrode pair and middle three are used as CuBr reservoirs. Inter-electrode separation is 50 cm. The electrode pin is of tungsten and is surrounded with OFHC copper turnings**.** The electrodes were sealed to the tube through "tungsten-molybdenum foil fused silica" sealing, which can carry an r.m.s. current of up to 20 A. A thin layer of alumina fibre blanket is wrapped around the laser discharge tube over the discharge zone to avoid heat losses. At the ends of the laser discharge tube, fused silica windows are attached at ~5^0 to prevent undesired resonator formation by feedback from the windows. The three middle side arms are loaded with ~50 g of distilled crystals of CuBr (purity > 99%). External electrical heater is used on these side arms to externally heat them in a controlled way to control the pressure of CuBr vapour in the discharge zone.

Assembly of the laser discharge tube was tested to have a leak rates less than 10^{-9} mbar-ltr/s. It was cleaned by discharge processing and evacuation cycles for about 30 hours before sealing. The laser discharge tube thus processed was sealed with neon buffer gas at 28 mbar pressure. The sealed -off lifetime depends on the mass of the CuBr loaded, vacuum integrity of the electrodes, window coatings, and bromine partial pressure. The laser is operated with CuBr reservoir temperature of around 435 ^{0}C. The laser system is shown in photograph in Fig.L. 8.2.

A high voltage, air cooled, pulsed power supply, operating from single phase mains, has been developed for this laser. Insulated Gate Bipolar Transistor (IGBT) rated for 1200 V, 400 A is used as the pulse power switch and two stages of magnetic pulse compressors are used to obtain pulse voltage of 12 kV with a rise time ~100ns across the laser discharge. Although the power supply has average power capacity of 1.1 kW, the laser is normally operated at around 600 W of average electrical power, at 17 kHz pulse repetition rate. The power supply is accommodated in a 19 inch standard sub-rack with height ~267mm.

The sealed-off CuBr laser is operated with a plane–plane resonator and it gives a maximum average power of 4.5W. During initial 100 hours of operation, the