F) Video Conferencing Setup Utilization:

Twenty promotion interviews were successfully conducted in RRCAT, using the Inter DAE video conferencing setup, of which RRCAT is one of the nodes. Large number of video conferences have been successfully conducted with various international research centres like CERN and FNAL. Now the video conferencing setups are in regular use.

G) Expansion of Telecommunication Network:

Telecommunication facilities were extended to the Laser R&D block H, Laser R&D block A-annexe, and RF Lab buildings. Mobile facilities were enabled on 24 extensions and 132 new telephone connections were installed in RRCAT campus. Revamping of 27 TDPs has been carried out to strengthen the telephone cabling network in the campus.

H) User Training - Z Drive Access:

A brief training session was conducted to familiarize the users working for International Linear Collider (ILC) collaboration at RRCAT, about the usage and various other security aspects of the new Z drive facility, which can be used for file sharing and other collaboration activities.

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T.1 : A study of diode pumped solid state lasers

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Technological advances in the recent years have resulted in the development of reliable laser diodes. Solid-state gain mediums doped with Nd^{3+} active ions can be pumped by laser diodes operating at 809 nm. Due to the excellent spectral overlap between the emission spectrum of the laser diode and the absorption spectrum of the gain medium at the pump wavelength, diode pumped systems have high overall efficiency. Moreover, these diode lasers have more than 10,000 hr lifetime in CW mode of operation. Diode laser pumping gives rise to a reduced heat load in the gain medium and there is no risk of UV radiation induced damage as compared to flash lamp pump systems.

There are two types of pumping schemes widely used in practice: 1) side pumping, and 2) end pumping. The end pumped systems have lower value of absorbed pump power at laser threshold, better beam quality, and higher efficiency than the side pumped versions. Moreover, it is the preferred pumping scheme when Nd:YVO_4 type of gain medium is used, due to the limited size of the laser crystal. As a result of the strong pump absorption coefficient at 809 nm, more than 95% pump absorption take place in a crystal as small as 0.3 mm thick.

A diode end pumped Nd:YVO_4 laser typically oscillates in multi-longitudinal modes, but with special techniques, it can be forced to operate as a Single Longitudinal Mode (SLM) laser. SLM lasers operate only in one of the allowed cavity modes. They are used in : wind velocity measurement, LIDAR, high-resolution spectroscopy, coherent optical communications, resonant cavity doubling etc. A compact and efficient SLM laser at 1064 nm may be realized in a diode end pumped Nd:YVO_4 laser based on a semi-monolithic type of gain medium in a standing wave cavity. However, certain applications demand single frequency operation of the laser output. A single frequency laser operating at a given wavelength demands that it should oscillate in SLM, single transverse mode (STM), and single polarization mode (SPM). A linearly polarized mode with diffraction limited transverse beam profile (M^2~1) would be preferred due its wider spectrum of application than the other modes of operation. This article presents our studies on the diode pumped single frequency laser generation in semi-monolithic Nd:YVO_4 gain medium and the technique adopted to extend its usefulness to other wavelengths by harmonic generation (1064 nm / 532 nm / 266 nm).

In our studies, we used semi-monolithic crystals as the gain medium. These are gain media, where a dichroic end mirror is directly coated on one side of the crystal itself. The dichroic end mirror provides high transmission at the pump wavelength and high reflection at the laser wavelength. Such a gain medium is beneficial for SLM operation. In addition, Stefen *et al* [1] have demonstrated that when the gain medium is situated close to an end mirror, we could obtain thermal lens insensitive resonator design by choosing a resonator with g_1g_2 of 1/2. The existing definitions of resonator stability, either in terms of g_1g_2 formalism or (A+D)/2 formalism, provides only a range over which the resonator is stable, but does not discriminate any value in between. We proposed a new definition of stability, which expresses the stability in a numerical scale ranging from zero to 100%, with 100% corresponding to g_1g_2 of 1/2. The proposed definition - the Degree of Optical Stability- was characterized by the S parameter expressed [2,3] in three different forms for convenience as,

$$S = 1 - \left[\frac{A(z) + D(z)}{2}\right]^2 \tag{1}$$

$$S = 1 - (2g_1g_2 - 1)^2 \tag{2}$$

$$S = \left[B(z_0)/Z_{R0}\right]^2 \tag{3}$$

where $0 \le S < 1$, $S < 0$, and $S = 0$ corresponds to stable resonator, unstable resonator, and marginally stable resonator, respectively. Here, A, B and D are the elements of round trip ABCD matrix, and Z_{R0} is the Rayleigh range in free space. We also studied the S parameter for a plano-concave cavity with plane mirror acting as the output coupler, and the gain medium kept very close to the curved input coupler. We also measured the misalignment tolerance of the cavity at the plane output coupler and tried to correlate it with the measured S parameter. The results are shown in Fig.T.1.1. The measured value of the S parameter was closely matching with the predicted values within the experimental error. In addition, it was found that the misalignment tolerance of the cavity was a maximum for S > 60%. Thus, we choose S > 60% in all our designs. However, effort was also put to increase the S parameter closer to 100%, to have thermal lens insensitive design. Keeping this in mind, we carried out a study of diode pumped single frequency laser generation in semi-monolithic $Nd:YVO_4$ gain medium.

The common technique to achieve SPM in a resonator is either by inserting a Brewster plate inside the resonator, or by using a gain medium with inherent gain anisotropy.

The inherent gain anisotropy existing in a-cut $Nd:YVO_4$ laser was used in our designs to get SPM operation. When an intracavity NLO crystal such as type-II phase matched KTP crystal is used for frequency doubling, the wave plate action in KTP crystal can severely affect the SPM operation. According to the theory of Helmfrid and Tatsuno [4], a-cut $Nd:YVO_4$ / KTP laser support SPM up to 28 times the laser threshold, as we increase the pump power. To enhance the SLM performance, an additional Brewster plate is also sometimes inserted in between the KTP crystal and the $Nd:YVO_4$ crystal. From our experimental studies, we found that the insertion of the Brewster plate delays the onset of the multi polarization significantly, and SPM is supported in such a cavity up to 73 times above the lasing threshold.

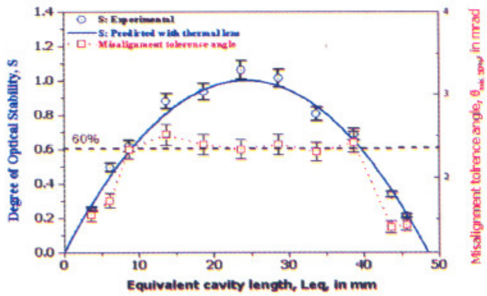

Fig.T.1.1. Measured S parameter using Eq. (3) and the predicted S parameter using Eq. (1) along with the measured value of the misalignment tolerance of a plano concave cavity as a function of the cavity length.

Two common techniques to achieve STM operation in a resonator are (1) using a hard aperture and, (2) by using the inherent gain aperture effect in an end pumped gain medium. The transverse variation of gain due to the spatial intensity profile of the laser diode (pump source) generates soft aperture effects in the resonator. This enables compact laser design with diffraction limited laser output. In a gain aperture governed system, the M^2 parameter of the output laser beam M^2_{GA} is related to the spot-size ratio R_{pm} as,

$$M^2_{GA} = k\, R_{pm}^{\;2} \tag{4}$$

where,

$$R_{pm} = \left(\frac{W_p}{\omega_{gm,00}}\right) \tag{5}$$

Here, k is the scale factor known to be unity for a diffraction limited pump source. In the above equation, W_p stands for the pump spot-size and $\omega_{gm,00}$ represent the TEM_{00} mode spot-size at the gain medium. We use fiber coupled laser diodes as the pump source, which have circularly symmetric and nearly Gaussian type of spatial intensity profile. However, they do not belong to the category of diffraction limited and have $M^2 \sim 25$. The value of the scale factor k is not known from literature. Thus, we decided to investigate the k parameter in an end pumped resonator using a fiber coupled laser diode as the pump source. It was found that when the spot-size ratio $R_{pm} < 1$, the laser output was nearly diffraction limited with $M^2 < 1.5$. However, as we increased the $R_{pm} > 1$, higher order transverse modes were generated and this resulted in a quadratic variation of the M^2 parameter. A least-square fit reveals that best fit for the value of the k parameter was 0.98 ± 0.02. Thus, k parameter is unity within the experimental error. In fact, we adopted a novel technique : the *two spot method,* to measure the M^2 parameter. Before using the technique, we checked the accuracy of the method by bench-marking it with a standard technique and was found to be accurate (error was < 3%).

We also studied the effect of spherical aberration of the beam transfer optics used to transfer the pump beam to the laser medium. The spherical aberration effects at the lens surfaces in the pump beam transfer optics can result in a significant degradation of the pump beam. This may result in an increased M^2 parameter of the pump beam after passing through such optics and the focused pump waist-size may not follow simple ABCD propagation model. The existing model to predict the degradation in the M^2 parameter due to spherical aberration effects was originally proposed by Siegman [5] and experimentally found to be accurate for diffraction limited laser beams. The model predicts that if the laser beam spot size at the lens location (W_L) is greater than a critical spot-size W_q, it results in an increase of the M^2 parameter of the laser beam, which depends on $(W_L/W_q)^4$. The spherical aberration effects will be absent if $W_L << W_q$. The validity of the model was tested with diffraction limited ($M^2 \sim 1$) input beam by Siegman [5] and was found to be accurate. However, the validity of the same model for input beams with $M^2 >> 1$ was not studied earlier. Hence, we decided to study the model using a laser diode beam with $M^2 \sim 25$. Fig.T.1.2 shows the increase in the M^2 parameter due to spherical aberration, when the output from a fiber coupled laser diode was transferred though a plano-convex lens with 25 mm focal length. To study the effect of spherical aberration, the spot-size at the lens location was varied by adjusting the separation between the fiber tip and the lens from ~25 mm to 50 mm. It may be observed that the measured M^2 varies from ~25 to 95. However, the M^2 predicted by the Siegman's model vary over a larger range from ~25 to ~386. This may be because multi-transverse mode beams ($M^2 > 1$) may have a larger spot size at the lens location ($W_L(z) \sim \sqrt{(M^2)}\ \omega_L(z)$) as compared to diffraction limited TEM_{00} Gaussian mode with a spot size of ω_L (z) at the same location. The larger spot-size at the lens location may be the reason behind the over-estimate. Therefore, a correction factor was incorporated in the existing model to scale up the critical spot size to result in a lower value of the M^2 parameter in multimode laser diode beams. It was found that a correction factor of 1.4 was required to explain the experimental observations. In addition, the existing model for the prediction of the focused pump waist-size was modified to satisfy the constraint that the spot size at the two principal planes of the lens must be same. The modified model could explain the experimental observations accurately.

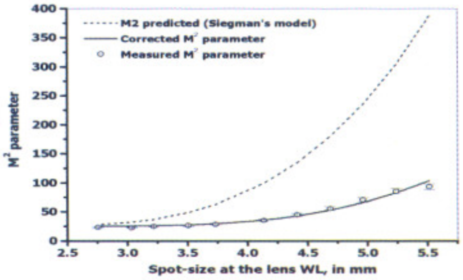

Fig.T.1.2. Variation of M^2 due to spherical aberration and the theoretically predicted variation according to the Seigman's model (dotted line). The solid line shows the variation in M^2 parameter after applying the correction to the critical spot-size predicted by Seigman's model.

The field of SLM operation of the semi-monolithic $Nd:YVO_4$ crystal at 1064 nm was investigated both theoretically and experimentally. The SLM operation is understood as due to the effective suppression of the spatial hole burning effect, up to a certain pump power above the lasing threshold and is characterized by r_{max} parameter [4]. On the theoretical front, the existing model by Helmfrid et al. [4] (referred to as HT model) was extended to overcome the shortcomings due to various assumptions involved. In fact, the HT model was derived in Ref. 4 for the special case assuming

[A1] Dephasing is small within an absorption depth

[A2] First oscillating mode is exactly at the line centre.

[A3] Narrow band (frequency) pump is used for optical pumping.

Because of the assumption A1, the model could not explain the observed enhancement in the r_{max}-parameter with increase in the axial mode separation. Hence, the first task was to remove the first assumption and rederive the model. The new model shows that r_{max} parameter does have a strong dependence on the axial mode separation [6]. This was verified experimentally [6]. Fig.T.1.3 shows the results of the measurement and the predicted variation of the r_{max} parameter with the axial mode separation. The matching between the theory and experiment was found to be very good. The role of active etalon effects [7,8,9] in semi-monolithic gain medium on the SLM performance was also studied.

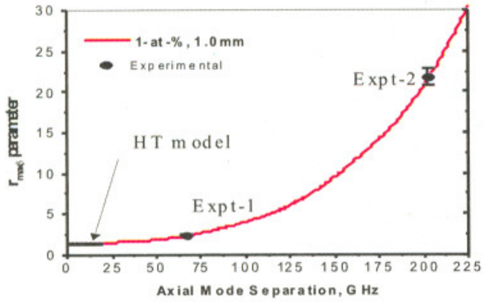

Fig.T.1.3: Predicted variation of the r_{max} parameter as a function of the axial mode separation in Nd:YVO_4 laser. The plot also shows the result of two experimental measurements. The validity of the existing HT model is also marked.

The second task was to remove the assumption A2 also. The new model correctly predicts that SLM performance deteriorates significantly (i.e. r_{max} parameter reduces) with shift in the location of the first mode away from the line centre [10]. The third task was to remove the assumption A3, while retaining the other two. This was done to simplify the results of the analytical model. The new model reveal that SLM performance deteriorates when pump diode with multi-longitudinal mode spectra with significantly high bandwidth is used as compared to a narrow band pump tuned to the absorption peak of the laser crystal [11]

All the above mentioned ideas were used to develop diode end pumped single frequency lasers at 1064 nm, 532 nm and SLM laser at 266 nm.

1. Compact single frequency IR laser at 1064 nm:

To ensure SLM, an a-cut Nd:YVO_4 crystal with very strong absorption coefficient at the pump wavelength (~ 111 cm^{-1}) was used. A compact plano-concave cavity with ~ 6.7 mm length and 75% stability (i.e. S parameter) was used as the resonator. The active etalon effects in the gain medium (Free Spectral Range, FSR ~129 GHz) enhanced the allowed range of SLM operation [12]. SLM operation was possible up to 5.62 times the threshold [13]. The output power of the laser was more than 100 mW. Fig.T.1.4 shows the photograph of the diode pumped single frequency IR laser with 110 mW output power. The output was linearly polarized with more than 10^4:1 polarization ratio. The spatial profile was a circular Gaussian with 0.5% astigmatism. Gain aperture effect was used to get diffraction limited laser output. The measured M^2 parameter was 0.99 ± 0.08. The RMS power fluctuation of the laser output was ~1% after a warm up to 30 min [12]. Fig.T.1.5 shows the power stability recorded at 100 mW output power.

Fig.T.1.4. Photograph of the diode pumped single frequency IR laser at 1064 nm. The power meter display shows ~ 110 mW.

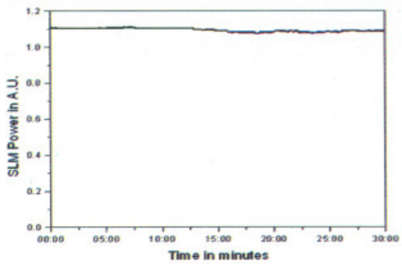

Fig.T.1.5. Power stability of 100 mW single frequency IR laser at 1064 nm.

2. Highly efficient single frequency green laser at 532 nm:

The usefulness of the single frequency laser at 1064 nm was extended to 532 nm, by intracavity frequency doubling using a 7 mm long type-II phase matched KTP crystal. A folded V- cavity with ~99.6% stability (both in sagittal and tangential direction) was used as the resonator. The cavity consists of Nd:YVO_4 / Brewster plate / KTP with the end mirrors directly attached tot the Nd:YVO_4, and KTP crystal. Simultaneous use of multiple effects ensured SLM operation. A 2% doped a-cut Nd:YVO_4 gain medium with 72.4 cm^{-1} pump absorption coefficient at 809 nm provided short-absorption depth effects to enhance SLM. The active etalon effects in the gain medium with 66 GHz FSR in combination with a birefringent filter of 250 GHz FSR ensured SLM operation. Fig.T.1.6 shows the photograph of the single frequency green laser at 532 nm operating with ~204 mW output power. Fig.T.1.7 shows the SLM signature recorded using a scanning confocal spectrum analyzer with a resolution of 7.5 MHz and FSR of 1500 MHz. Measurements revealed that the line-width of the 532 nm laser was ~17 MHz. Polarization measurements of the green output revealed that it was linearly polarized with more than 100:1 polarization ratio. The M^2 parameter measured at 532 nm was ~1.07. The system generated more than 270 mW of single frequency green emission with more than 33.7% optical-to-optical power conversion efficiency from 809 nm to 532 nm [14]. This is the highest efficiency reported in the literature, for a diode pumped single frequency $Nd:YVO_4$ / Brewster plate / KTP laser at 532 nm.

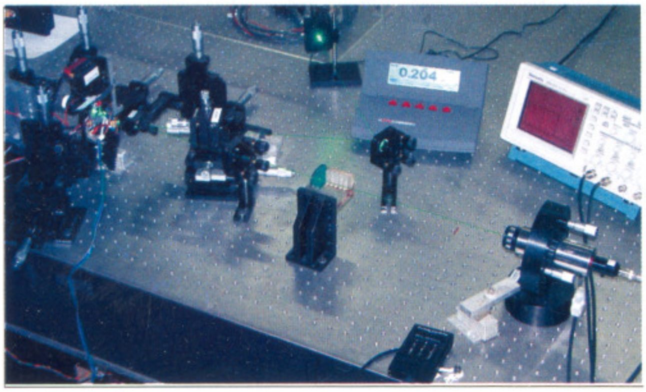

Fig.T.1.6. Photograph of the single frequency green laser at 532 nm operating with ~204 mW output power.

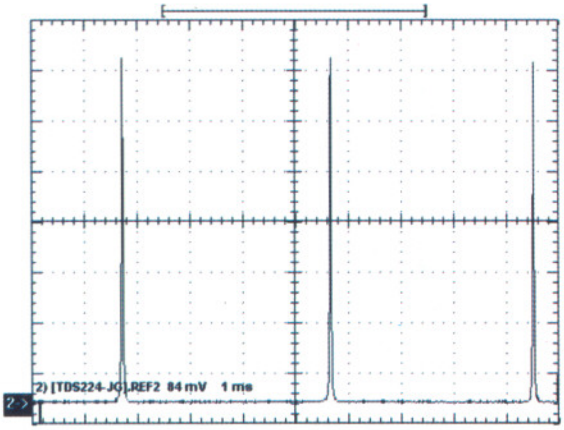

Fig.T.1.7: SLM signature of the single frequency green laser at 532 nm measured using a scanning confocal spectrum analyzer with a resolution of 7.5 MHz and free spectral range of 1500 MHz.

3. SLM laser at 266 nm by resonant doubling:

The usefulness of the single frequency green laser was further extended to ultraviolet (UV) regime by intracavity doubling in a frequency locked slave ring cavity using a 7 mm long β-BBO crystal. Fig.T.1.8 shows the schematic of the experimental set-up. Hansch-Couillaud based scheme was used for frequency locking. The necessary negative feedback control electronics was also developed for frequency locking [15]. The ring cavity was designed to have 100% stability in the sagital direction and more than 94% stability in the tangential direction. The transmission of the input coupler chosen was 2.1% to ensure impedance matching. The system generated more than 3.4 mW of UV power at 266 nm at an incident pump power of 225 mW at 532 nm [16].

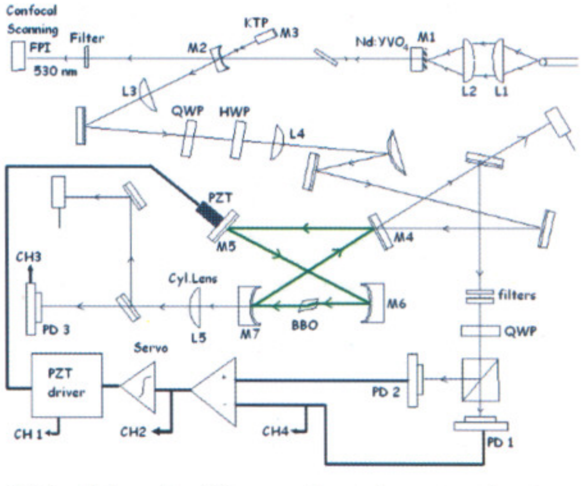

Fig.T.1.8. Schematic of the experimental setup used to generate SLM UV laser at 266 nm by resonant cavity doubling technique.

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T.2 : Research activities using the synchrotron radiation source : Indus-1

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This article reviews the various science and technology experiments performed on Indus-1 over the last four years. The objective of this article is to highlight the scope of Indus-1 synchrotron facility with few specific examples, and to encourage more users to come forward in planning experiments with Indus-1.

Indus-1, a 450 MeV electron storage ring, is a good source in soft x-ray / vacuum ultra violet (40 to 1000 Å) and infrared regions of the electromagnetic radiation spectrum. The critical wavelength of the emitted synchrotron radiation is 61 Å. The electron beam completes the closed orbit path using four 1.5 T bending magnets (BM) with a bending radius of 1 m. Each BM vacuum chamber has two synchrotron radiation ports. Fig.T.2.1 gives the schematic representation of Indus-1 storage ring along with location of various beamlines. These beamlines have been installed on three BM ports (DP1, DP2, and DP3). At present, on Indus-1, five beamlines are operational. On DP1, high resolution vacuum ultra violet (VUV) spectroscopy beamline and photo electron spectroscopy (PES) beamline; on DP2, angle resolved photo electron spectroscopy (ARPES) beamline and soft x-ray-VUV(SXUV) reflectivity beamline; and on DP3, photo physics beamline are installed. Efforts are underway to install an infra red beamline on DP3. Front end of SXUV reflectivity beamline on DP2 is being modified to accommodate a photo absorption spectroscopy (PAS) beamline. Characteristics of the various beamlines operational on Indus-1 are given in Table-1. Details of the Indus-1 and various beamlines are available in *Current Science* as a special section: "Indus-1 synchrotron" [1] and in Indus-1 Activity Report 2003 [2].

Soft x-ray–VUV reflectivity beamline

The soft x-ray-VUV (SXUV) reflectivity beamline has reflectometer and time of flight mass spectrometer as experimental stations. The reflectometer station is used for the investigation of optical response of various materials with emphasis on measurements near the absorption edges, where experimentally measured response is scarce. The focus is to undertake interface studies in thin films structures and for testing the performance of the soft x-ray optics at the designed wavelength. The reflectometer is equipped with two axis high vacuum compatible goniometer operating at ~10^{-7} mbar vacuum [3]. The design and fabrication of optical devices in x-ray region require reliable knowledge of the soft x-ray optical response of the materials. The penetration of soft x-ray