L.3: 70% enhancement in output power capability of a wide aperture copper vapor laser with hydrogen additive in its neon buffer gas

Standard copper vapor lasers with moderate tube bore of 45-50 mm bore, simple C-C discharge circuit and using pure neon as buffer gas are severely limited by output power capability to ~ 30-35 Watt at 5-6 kHz rep-rate. Also due to load mismatch conditions this type of CVLs often encounter latch-on conditions of high voltage switch thyratron resulting in possibility of frequent disruptions in their continuous operation.

Use of hydrogen in its buffer gas in highly optimized proportion results in enhanced performance with increase in output power, operating frequency (rep-rate) and efficiency with better load matching conditions. So far 50 % maximum increase in output power on using hydrogen as additive has been reported in literature in a small bore CVL device and 25-30 % in case of wide aperture CVL systems. The presence of hydrogen in buffer gas ensures better inter-pulse plasma relaxation, removal of excess electrons from discharge by process of disociative attachment (DA) and maintains high discharge voltage due to reduced conductivity between laser electrodes. In house development of a simplified rate equation model for CVL system by us also reveals increase in CVL gain on reducing the pre-pulse electron density. This confirms the main role of hydrogen as an additive in enhancing the CVL performance significantly.

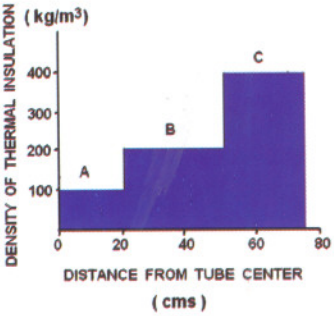

Fig.L.3.1 Longitudinal profiling of thermal insulation around discharge tube

We recently demonstrated in our laboratory, a standard 30 Watt CVL with hydrogen additive and achieved power enhancement of ~ 70 % with output power achieved in excess of 50 Watt at ~ 10-11 kHz rep-rate. The CVL was based on 47-50 mm bore x 1500 mm length discharge tube with modified (longitudinally profiled) thermal assembly around it to ensure minimum end thermal losses and increase in tube temperature to ~ 1600 ° C (Fig.L.3.1). Fig L.3.2 show laser power buildup with time with hydrogen additive. The high enhancement achieved is due to fine optimization of hydrogen content, increased tube temperature to 1600 C using new thermal assembly and better load matching conditions Fig. L.3.3 show CVL operating with hydrogen additive with maximum power of 54 Watt at 11.5 kHz

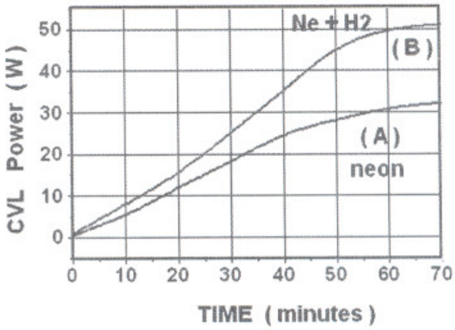

Fig.L.3.2 Laser power buildup with time : (A) with pure neon. (B) Neon + hydrogen

Fig.L.3.3. CVL operating with hydrogen additive delivering 54.6 W at 11.5 kHz rep-rate

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L.4: Measurement of Nanometer scale-Optical Path Length Variations Using Phase Sensitive Spectral-Domain Optical Coherence Tomography

Optical coherence tomography (OCT) can provide non-invasive cross-sectional images of biological microstructures in real time with resolutions down to few micrometers. Spectral domain OCT retrieves depth information in the sample by the Fourier transformation of the intensity of the interferometric signal as a function of optical wavelength without the need for reference arm scanning. The phase of the interferometric signal can be used to detect the sub-wavelength variations in the optical path of the interferometer. Choma et al [*Opt. Lett. 30, 1162 (2005)*] used a spectral domain OCT (SDOCT) system for retrieval of quantitative phase information to measure variations in optical path length (OPL). Even though their OPL sensitivity is ~53 pm, the approach is limited only for $\sim\lambda/2$ optical pathlength change due to the 2π ambiguity. The measurement of longer ($>\lambda/2$) OPL changes require phase unwrapping to overcome the 2π ambiguity. Zhang et al [*Opt. Lett. 34, 3442 (2009)*] has shown high dynamic range phase changes (34pm to 2mm) using Fourier transform method and phase unwrapping. In this report we present an approach of phase-sensitive Spectral domain OCT using Hilbert transformation of the acquired spectral interference fringes. It can give absolute optical path length with nanometer-scale variations.

The real-time SDOCT system (Fig. L.4.1) developed at LBAID, RRCAT consists of a superluminescent diode (SLD) of center wavelength 840nm with bandwidth ~40nm. The output of the SLD is coupled in to a 3dB fiber coupler. One arm of the coupler was left open while the other arm of the coupler was used as common path interferometer to eliminate the environmental dependant common mode noise in the sample and reference path. In our setup the sample chamber itself provides the reference beam required for the interference as shown in inset Fig.L.4.1. In the detection arm of the fiber optic interferometer, the light was collimated and diffracted with a transmission grating (1200 lines per mm). A 150 mm focal length lens was used to focus the diffracted beam on a line scan camera (Atmel Aviiva) for acquisition of the interferometric signal.

For a given sample the spectral distribution of the light at the line scan camera (LSC) has the sinusoidal interference ($u(k) \propto \cos(kz)$) superimposed on the broad source spectrum. This sinusoidal term was separated by Fourier filtering of the acquired data. The complex analytical interferometric signal can be obtained using Hilbert transformation $w(k)=u(k)+iHT/u(k)$. The phase of the interference signal can be calculated as $\Phi(k)=\tan^{-1}[Im(w(k))/Re(w(k))]$ The unwrapped phase of a sinusoidal function ($u(k)$) varies linearly and the absolute optical path can be observed by measuring the slope of Φ-k curve.

For experimental demonstration of the high-resolution path length measurements, the SDOCT set up was used to acquire the optical path length for air and water.

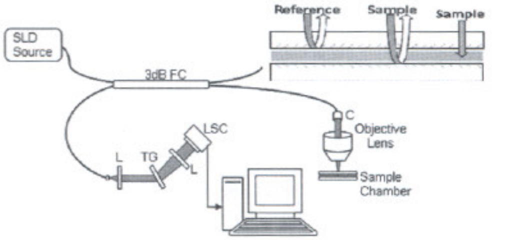

Fig.L.4.1. Schematic of SDOCT system. SLD: superluminescent diode, FC: fiber coupler, L: lens,TG: transmission gratng, LSC: line scan camera. Inset shows the schematic of the common path geometry.

The acquired interference spectra for air (empty) and water filled chamber are shown in Fig. L4.2a. The inset shows the fringe shift shown in Fig. L4.2a. The phase slope measured with Hilbert transformation for these two cases are shown in Fig. L4.2b. Here, the inset shows the optical path measured for empty chamber for 800 spectra. The measured optical path length for air chamber was 194781nm with standard deviation (σ) ~26 nm. The measured optical path length for the water filled chamber was 260638nm which leads to refractive index of water ~1.3381 with standard deviation $\sim 3x10^{-4}$. The measured error for the refractive index measurement is ~100 times smaller than that obtained using the intensity based OCTmeasurements.

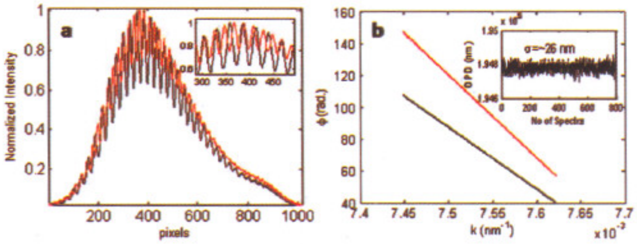

Fig. L.4.2 (a) Interference spectra acquired for air and water filled chamber. Inset shows the zoomed fringe shift for better clarity. (b) Unwrapped phase slope measured for these two cases. Inset show the optical path stability measured for empty chamber for 800 spectra.

In summary, we have shown the measurement of absolute optical path length with ~26nm standard deviation (in air) using Hilbert transform phase calculations. The set-up is being used to measure small index/thickness variations in biological samples.

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