L.6: 20 kHz, efficient operation of a large-bore copper vapor laser (KE-CVL)

Laser System Engineering Division (LSED) has been working on the development of wide bore CVL lasers for the last few years. (Ref: "100 W kinetically enhanced copper vapor laser at 10 kHz rep-rate, high (1.5 %) efficiency, low (1.6kW/l) specific input power and performance of new resonator configurations"; Bijendra Singh, et.al.; Optics Communications Vol 281, p.4415 2008). Wide aperture elemental copper vapor lasers are optimized at moderate operating frequency (rep-rate) of ~ 4-5 kHz, due to limitations of radial discharge penetration (skin effect) and longer meta-stable deactivation time of lower laser level by wall collisions. Increase in frequency results in drastic reduction in CVL output power/efficiency to unacceptable levels. The operating frequency of a CVL can be boosted several times (3-4 times) without degrading its output power/efficiency using kinetically enhanced (KE) techniques, in which specialized buffer gas mixture consisting of hydrogen ~ 1-2 %. HCl ~ 0.5 % and balance as neon is used in highly optimized proportion. The dissociative attachment (DA) properties of hydrogen and HCl favorably controls the pre-pulse electron density and also the inter-pulse plasma is relaxed efficiently. Higher operating frequencies are desirable in CVLs for their various applications and experiments such as femto-second pulse amplifications. Single high rep-rate CVL system also avoids complicated multiplexing techniques and beam combiners etc.

We recently demonstrated the operation of a standard CVL in KE mode to operate at ~ 20 kHz efficiently. The KE-CVL was based on 50 mm bore x 1500 mm length discharge tube and was capable of delivering about ~ 30 Watt power as a standard CVL in non-KE mode of operation at ~ 5 kHz rep-rate. On operating the laser in KE mode the highest operating frequency achieved was about ~ 20 kHz with output power of ~ 35-40 Watt. Thus a record enhancement of 4 times in operating frequency was achieved without loss of power with respect to its standard operation (non -KE) in this indigenously developed KE-CVL.

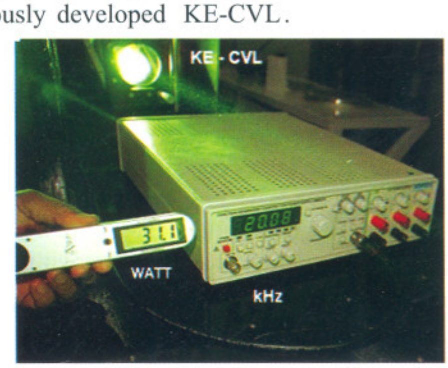

Fig L.6.1 CVL operating at 20 kHz

Fig L.6.1 shows laser operating at 20 kHz rep-rate. Table 1 lists laser power at other operating frequencies at constant input power of ~ 5 kW.

Table. L.6.1 : Performance of laser at various rep-rate

Rep-rate	Laser power	Mode of operation	Buffer gas Composition
5 kHz	30 W	Standard non-KE	Pure Neon
10 kHz	74 W	KE	H_2+ HCl + Neon
15 kHz	50 W	KE	H_2+ HCl + Neon
17 kHz	44 W	KE	H_2+ HCl + Neon
20 kHz	35 W	KE	H_2+ HCl + Neon

This is the first efficient demonstration of a large-bore elemental CVL at 20 kHz and to the best of our knowledge, has not been reported so far in the published literature.

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L.7: Dynamics of cold Rb atom cloud in a magneto-optical trap

Magneto-optical trap (MOT) has become a robust tool to cool and trap neutral atoms to explore both fundamental aspects of atomic physics and possible applications in the frontiers of quantum computation and information processing. Laser Physics Applications Division at RRCAT has developed a MOT which typically consists of a combination of three pairs of appropriately polarized counter-propagating laser beams intersecting at the zero of an externally applied quadrupole magnetic field. The cold atom cloud is obtained at the centre of the trap with temperature of nearly few hundreds of micro-Kelvin. Recently, the dynamics of cold rubidium (^{85}Rb) atom cloud in the MOT was investigated using a pulsed forcing laser beam. The impulse imparted to the atom cloud was measured in terms of its initial drift velocity.

Fig.L.7.1 shows the schematic diagram of the experimental setup. The time-of-flight (TOF) method was used to estimate the drift velocity and velocity width of the forced atom cloud. A continuous weak laser beam of nearly constant intensity and height of 200 μm was derived from the

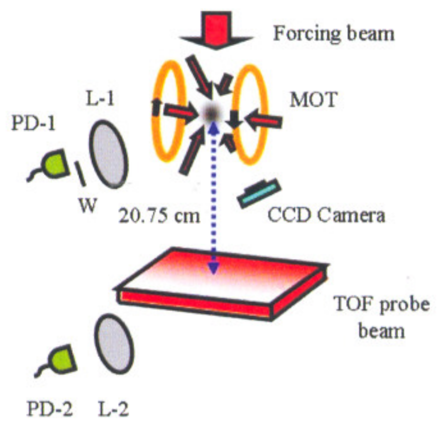

Fig.L.7.1 Schematic of the experimental setup.

trapping laser to obtain the fluorescence from the falling atom cloud. It was kept 20.75 cm vertically below the trap centre and was retro-reflected to make a standing wave to avoid the pushing of the falling atom cloud away. The fluorescence was recorded by a low noise level photo-detector (PD) to observe the TOF signal (Fig.L.7.2) as a function of arrival time of the atom cloud at the probe beam. The drift velocity and the variance of the velocity distribution of atom cloud were estimated by fitting experimentally observed TOF signals with that calculated numerically. The forcing laser beam of variable pulse-width ΔT (50μs-250μs) was frequency locked at the centre of the cooling transition and was made to propagate along the vertically downward direction. In this range of ΔT, the initial drift velocity was observed to be varying nearly linearly from around 4 m/s to 16 m/s. The velocity width in this range was estimated to be ~1 m/s.

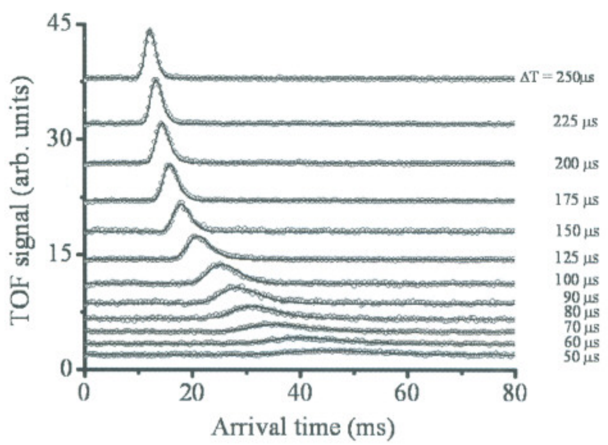

Fig. L.7.2 Experimental TOF signals denoted by open circle along with theoretically fitted solid curves for different forcing beam pulse-width ΔT.

Here, we have demonstrated for the first time a technique which can be used to study simultaneously the processes of trapping as well as the escape in the MOT. For smaller initial drift velocities (50μs-70μs), oscillations of the atom cloud resulted because of the recapture of the forced atoms by the trap. The fluorescence from the trapped atom cloud was collected by a lens (L) and passed through a wedge (W) on a low noise level photo-detector to observe the oscillatory motion of the atom cloud. With larger drift velocities, the atom cloud was found to traverse in the nonlinear region of trap with reduced trapping force with a tendency to escape from the trap. The drift velocity of the atom cloud at which nearly all the trapped atoms escaped from the trap provided an estimate of the escape velocity of the cold atoms.

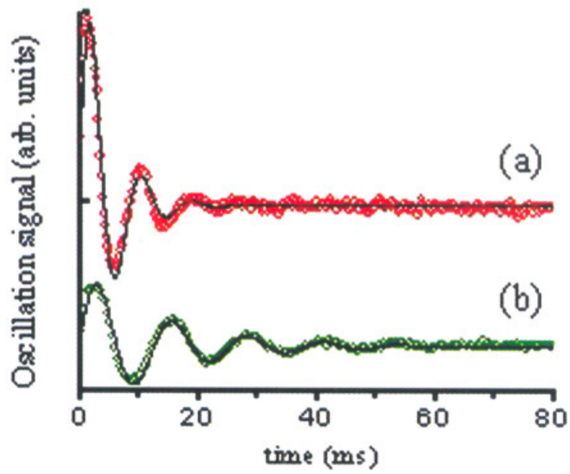

Fig. L.7.3 Damped oscillation signals for trap laser detuning (a) $\Delta_L = -2\,\Gamma$ and (b) $\Delta_L = -3\,\Gamma$ for forcing beam pulse-width $\Delta T = 50$ μs. The experimentally observed signals are denoted by open circle and solid lines are fitted curves.

Fig.L.7.3 shows the typical examples of experimentally observed oscillations in the fluorescence signals for two different trap laser detuning of $\Delta_L = -2\Gamma$ and -3Γ, where $\Gamma = 2\pi \times 5.9$ MHz is the natural line-width of the cooling transition. The single trapping laser beam intensity of 2.5 mW/cm^2 and magnetic field gradient of 12.5 G/cm were used. The observed values of spring constant, $\kappa = (8.02\pm0.11)\times10^{-20}$ N/m [$(3.34 \pm 0.11)\times10^{-20}$ N/m] and damping coefficient, $\alpha = (6.19\pm0.27)\times10^{-23}$ Ns/m [$(2.55\pm0.27)\times10^{-23}$ Ns/m] for $\Delta_L = -2\Gamma$ [-3Γ]. Due to the reduced value of spring constant and damping coefficient for the higher value of detuning, the period and number of oscillations observed for $\Delta_L = -3\,\Gamma$ were found to be more as compared to $\Delta_L = -2\,\Gamma$. The results of these investigations are expected to be useful in the studies of trap loss collisions, trap instability measurements and transfer of cold atoms.

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