# GENERATION OF A FREQUENCY COMB FOR WHITE-LIGHT LASER COOLING OF IONS IN A STORAGE RING

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## 1. ABSTRACT

The use of a "white-light" laser in a storage ring provides a radiation pressure force with wide velocity capture range which is promising to improve the performance of laser cooling. The "white-light" must have a sharp edge in order to reach the lowest temperatures. A frequency comb which satisfies the mentioned condition has been generated by successive frequency shift of a single mode laser by an acusto-optic modulator coupled to a passive ring cavity.

## 2. INTRODUCTION

The principle of white-light [1] is to make particles with different velocities resonant with the field, compensating for the Doppler shift by emitting the laser light in a large frequency range. The resulting radiation pressure force has a wide velocity capture range, which is of particular interest for improving cooling performances in presently running storage rings. In storage rings in fact there are violent collisions in the circulating ion beam, which make ions escape the laser cooling force. This calls for a strong force with a long tail at one side to recapture ions and a sharp edge on the other to reach the lowest temperatures [2]. It was the aim of our investigation the generation of a frequency spectrum with a broad band and a very sharp frequency cutoff.

## 3. WHITE-LIGHT IN STORAGE RINGS

Longitudinal cooling of ions in a storage ring can be obtained either by two counterpropagating laser beams, which compress the velocity distribution of the ions in their rest frame [3], or with a single laser beam in combination with a counteracting non resonant auxiliary force [4]. The dispersionlike shape of the force obtained with two counterpropapgating monochromatic laser beams is shown in Fig. 1.a . The arrow indicates the stable point towards which the ion velocity distribution is driven. The two characteristics parameters of the process are the cooling rate Λ which describes the efficiency of the cooling process and the capture range $\Delta v_C$ of the force [5]. In Fig. 1.b the cooling force induced by white-light laser is shown. It is evident that in the second case the ions remain in the the cooling cycle independently of the perturbations undergone during the trip in the storage ring. A large capture range can be achieved in principle also with a monochromatic laser by exploiting the power-broadening effect, but this requires irrealistically high laser power and causes a drastic reduction of the cooling rate [2]. It is worth mentioning that at TSR in Heidelberg a large capture range has been obtained with the help of local potential acting on the ions [6]. Also this solution anyway, presents a small cooling rate.

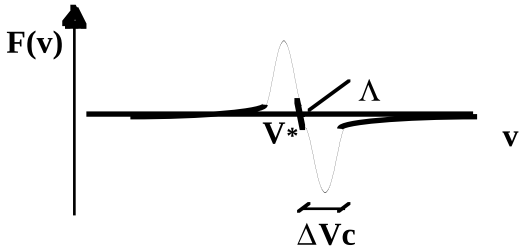


Figure 1.a Cooling force generated by two counterpropagating monochromatic laser beams.

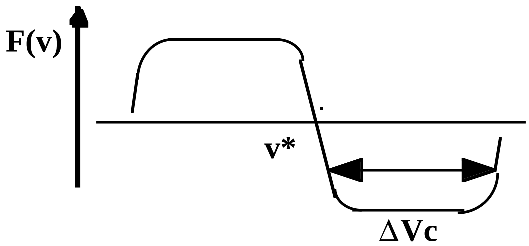


Figure 1.b Cooling force generated by two counterpropagating white-light laser beams.

The authors have previously discussed the possible implementation of direct and indirect transverse cooling by using a white-light source [2;7].

## 4. GENERATION OF A FREQUENCY COMB WITH A SHARP-EDGE.

### *4.1 Cavity configuration*

A new set-up which makes possible the generation of a frequency comb with fully adjustable sharp-edge [8] has been realized. We use a passive ring resonator closed by a frequency stabilized AOM. The cavity design is original as the laser-cavity coupling scheme which give the possibility to generate very intense and broad spectra. The frequency stability of the sharp edge is assured by the actively stabilized single mode laser, which is injected inside the cavity, and by the AOM stability. Moreover the sharp edge intensity can be easily controlled through the diffraction efficiency of the AOM. In our scheme, the input laser beam (1 mW single-mode He-Ne laser) is coupled into the ring cavity through the second AOM diffraction order as shown in Fig. 2. The direction of the traveling acoustic wave is shown by the arrow. The modulator is operated at $\Delta\nu_{AOM}$ = 60 MHz. The passive cavity is made by two rings intersecting at AOM level. Fig. 2 shows the path of the light in the cavity with the AOM switched off, evidencing the two rings.

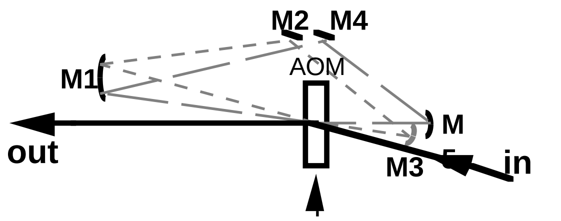


Figure 2. Sketch of the cavity configuration. The different dashed lines evidence the two intersecting rings. Mi = mirrors

When the modulator is switched on, the lowest frequency peak (the sharp edge) is generated by the light which is directly diffracted out from the input laser beam. Therefore, its intensity is totally controlled by the diffraction efficiency of the modulator. By taking into account the acoustic wave direction, the frequency of this peak is $\nu_{-2} = \nu_0 - 2\Delta\nu_{AOM}$, where $n_0$ is the injected laser frequency. The $\nu_{-2}$ frequency peak has, then, the same stability and width of the injected laser beam. Any other mode of the comb is made by two components following different path lengths inside the cavity. Both of them add coherently at the output and interference can be used to shape the spectrum by varying the relative positions of the mirrors. The total spectrum linewidth can easily be doubled by making the output beam crossing another acusto-optic modulator. In the present case we have used a device operating at 210 MHz and with an efficiency equal to 30 %.

## *4. 2 Experimental results*

The spectral distribution of the output beam has been recorded by scanning a confocal Fabry-Perot interferometer. In Fig. 3 the laser spectrum after the second modulator is shown. It demonstrates the very high efficiency of our scheme; the peak positions with respect to input laser frequency are also shown. The effective efficiency, i.e. the output light intensity over the input light intensity is higher than 80 % and the total bandwidth is about 0.5 GHz.

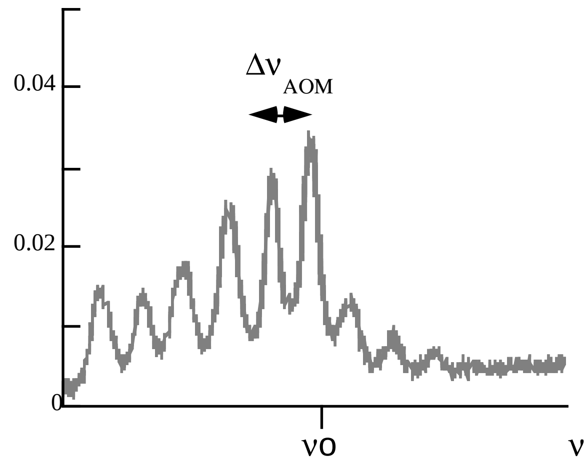


Figure 3. Fabry-Perot transmission of laser signal (arb.units) after the second AOM. The frequency of input laser is indicated by $\nu_0$.

## 5. CONCLUSIONS

The use of white-light should improve laser cooling performance in presently running storage rings. A large frequency comb with a fully controllable sharp edge has been generated. The obtained spectrum should allow a first test of laser cooling with a broad-band laser in a storage ring. A preliminary test is programmed at TSR in Heidelberg.

## 5. REFERENCES

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