High Power Generation of 257 nm Radiation for Laser Cooling of Relativistic $^{24}Mg^{+}$ Ions at the ESR

U. Schramm, A. Peters, and D. Habs

Laser cooling of bunched ion beams in storage rings has proven to produce beams with unprecedented high phase space densities [1], already giving access to a regime where the influence of longitudinal space charge effects becomes relevant. Damping the synchrotron oscillations of stored ions in the longitudinal RF potential via the spontaneous scattering force also indirect transverse cooling due to intra-beam Coulomb-scattering and very recently even direct transverse cooling exploiting the storage ring dispersion by a transverse gradient in the longitudinal cooling force could be observed at the TSR [1]. In contrast to these experiments performed at ASTRID and the TSR with low ion currents (e.g. 10^7 $^9Be^+$ ions for the TSR) we aim for highest intensity and brightness. Here an efficient coupling between the longitudinal and the transverse degrees of freedom is foreseen which should lead to fully space charge dominated intense beams possibly relevant e.g. for heavy ion driven inertial fusion concepts. Furthermore interesting new heating mechanisms may show up which have to be overcome by the 3D-cooling process.

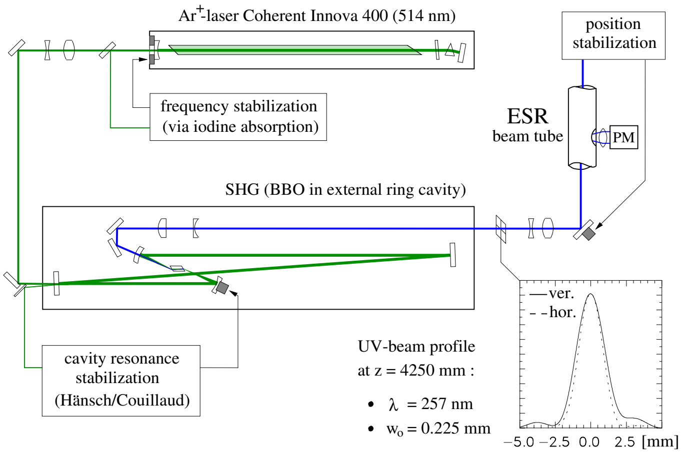

Fig. 1: Experimental setup prepared for laser cooling studies of 83.7 MeV $^{24}Mg^+$ ion beams at the ESR Darmstadt storage ring consisting of a frequency stabilized Ar^+-laser, a ring cavity for second harmonic generation and only sketched the optical system guiding the UV-beam position stabilized to one of the straight ESR sections. In the lower right corner the spatial UV-beam profile measured after beam shaping in the sagittal plane is shown, representing a near Gaussian profile.

The laser system we setup for cooling of 83.7 MeV $^{24}Mg^+$ ion beams at the ESR Darmstadt [2] consists of an Ar^+-laser stabilized via iodine absorption to the wavelength of 514.5 nm, a Brewster-cut nonlinear BBO crystal for second harmonic generation placed at the spherical focus of an external ring resonator which provides power enhancement of the fundamental wave, and the (position stabilizing) beam transport system to the ESR as shown in fig. 1. Here the longitudinal laser cooling process can be monitored via induced fluorescence of the circulating ions locally Doppler-tunable inside a high voltage drift tube.

From the quadratic dependence (left part of fig. 2) of the UV output power (measured after beam shaping) on the fundamental power stored in the cavity (monitored via the calibrated transmission of a cavity mirror) we deduce a remarkable conversion efficiency of η=9.3$\cdot 10^{-5}$ W^{-1} which still has to be corrected for the UV-transmission of the following cavity mirror (0.94) and for Fresnel-losses at the crystal exit surface (0.85). Therefore we obtain a maximum UV power generated without any degradation of the crystal of 750 mW [3].

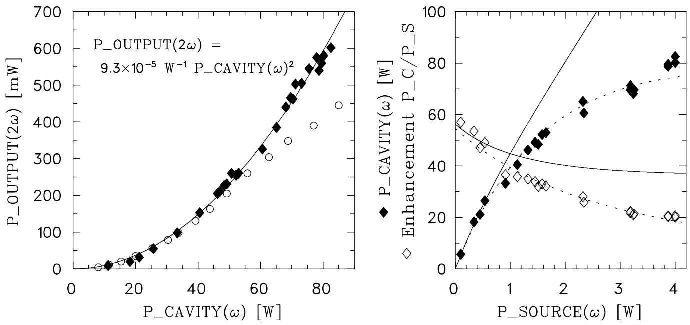

Fig. 2: Second harmonic output power as a function of the intra cavity fundamental power (left), the solid line representing the expected quadratic dependence, the open circles a measurement with a slightly misaligned cavity. The right figure illustrates the cavity performance, the power enhancement being reduced more strongly than anticipated (solid line) from the actual UV-conversion losses (dotted line) for a cavity power exceeding about 30 W.

Summarizing the completed SHG unit provides stable output power sufficient to saturate the desired $3^2S_{1/2} \rightarrow 3^2P_{3/2}$ cooling transition (I_{sat}=800 mW/cm^2) over a large area and therefore allows to exploit the novel dispersive direct transverse cooling scheme, recently demonstrated at the TSR. However, because of the diminished cavity enhancement for higher input power caused by thermal lensing inside the crystal and the fact, that a small misalignment of the cavity immediately leads to a significant UV-power reduction (compare open circles in fig. 2), it might be advisable to use two (identical) SHG units fed by the same stabilized Ar^+-laser for easier operation (at identical UV power) and to further prepare a broad band extension, effectually tested at the TSR [4]. Furthermore an easily modified version of the unit is planned to be used in connection with a tunable laser for laser cooling of $^{24}Mg^+$ in the presently built Paul-ring-trap PALLAS [5].

References

[1] U. Schramm *et al.*, this report, p. 40 and references therein.
[2] A. Peters *et al.*, Jahresbericht 1996, p. 107
[3] U. Schramm, A. Peters, D. Habs, submitted to Hyperfine Interactions (1997)
[4] S.N. Atutov, F. Bonazzi, R. Calabrese, V. Guidi, P. Lenisa, S. Petruio, E. Mariotti and L. Moi, Opt. Com. **132** (1996) 269 and S.N. Atutov, R. Calabrese, R. Grimm, V. Guidi, I. Lauer, P. Lenisa, V. Luger, E. Mariotti, L. Moi, A. Peters, U. Schramm, D. Schwalm, M. Stößel, submitted to Phys.Rev.Lett. (1997)
[5] T. Schätz *et al.*, this report p. 97