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

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At the storage ring ESR (GSI Darmstadt) we prepare the investigation of radio-frequency bunched ion beams with unprecedented phase space densities. To achieve such ion beams laser cooling has to prevent several heating processes like intra-beam scattering and space charge forces. It relies on repeated cycles of unidirectional absorption and isotropic spontaneous reemission of photons by ions. In the case of bunched ion beams the resulting momentum transfer in the laser beam direction leads to a damping of synchrotron oscillations and therefore to beam cooling. The laser beam will be collinearly merged with the ion beam in one of the straight sections of the ESR. Hence the laser cooling force acts directly in the longitudinal beam direction. Furthermore we expect efficient indirect transversal cooling [1] due to Coulomb collisions between the stored ions.

The electron shell of $^{24}Mg^+$ ions includes a closed two level system with a short lifetime ($\tau = 3.5\,\mathrm{ns}$) of the upper state optimally suited for laser cooling. The transition wavelength in the ion rest-frame amounts to 279 nm and the saturation intensity to $800\,\mathrm{mW/cm^2}$. We therefore chose to frequency double the strong argon ion laser line at 514 nm implying an ion velocity of 8.7 % c to Doppler-shift the transition wavelength to 257 nm.

At a first successful test of the injection scheme and the storage of $^{24}Mg^+$ ions in the ESR (Oct. 96) the residual gas pressure of estimated $(5\text{ - }10)\cdot 10^{-10}$ mbar limited the storage lifetime to 0.5 s - 1 s. After the scheduled bake-out of the ESR (spring 97) we expect an improvement of the vacuum conditions and the lifetime respectively by about one order of magnitude allowing for systematic laser cooling experiments.

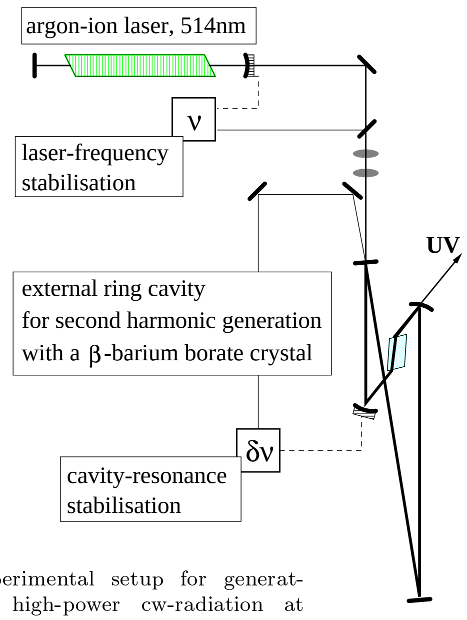

Fig. 1: Experimental setup for generating high-power cw-radiation at $\lambda = 257\,\mathrm{nm}$

Fig. 1 shows a schematic view of the laser system. A frequency stabilized argon ion laser provides the fundamental wave at $\lambda = 514\,\mathrm{nm}$ which is doubled by a 7 mm long Brewster cut BBO crystal. This crystal is placed in an external ring cavity to enhance the power of the fundamental wave. Typical enhancement factors in this cavity presently range from 36 to 42. The mirrors of the cavity are arranged in a double Z geometry so that the coma of the cavity is minimized and the astigmatism introduced by the spherical mirrors is compensated by the astigmatic effects due to the crystal. The two spherical mirrors around the crystal focus the fundamental wave at the center of the crystal where a waist radius of about 20 μm is reached. One of these mirrors is highly transmitting at 257 nm so that the produced UV light can be extracted from the cavity. The cavity is locked to resonance by the well established Hänsch-Couillaud scheme ensuring a stability of the UV power for several hours in our setup.

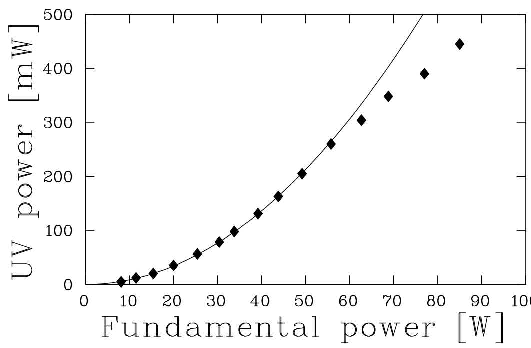

Fig. 2: UV power outside the cavity as a function of fundamental power stored inside the cavity. The UV beam emerging from the cavity was guided by UV mirrors and focused by a lens onto a power-meter based on a thermal disk sensor where the UV power was measured. The fundamental power inside the cavity was determined with the same power-meter by detecting the green light leaking through one cavity mirror with known transmittance. The solid line represents a quadratic fit to guide the eye.

The results of first measurements with the cavity are shown in fig. 2. As expected the measured second harmonic power in the power regime below 300 mW depends quadratically on the fundamental power. To specify the generated power inside the crystal one has to take into account transmission losses at the output mirror and Fresnel losses at the crystal exit face. Since fig. 2 shows the UV power outside the cavity the UV power inside the crystal has to be assumed about 25 % larger than the data shown. The experimental data in the regime above 300 mW reveal thermal effects due to absorption of UV radiation inside the BBO crystal. This is in good agreement with measurements reported in reference [2].

References

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