Towards Laser Cooling of Magnesium Ions for Sympathetic cooling of Highly Charged Ions at SPECTRAP

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Introduction: Experiments with highly charged ions (HCI), especially with H-like and Li-like ions are an excellent testing ground for quantum electrodynamics (QED) in strong electric and magnetic fields and for precise measurements of fundamental constants. At the ESR, an experiment is being prepared to search for the hyperfine transition in lithium-like $^{209}Bi^{82+}$ in order to disentangle nuclear structure from QED effects [1]. Subsequent precision laser spectroscopy measurements of these transitions are prepared by the SPECTRAP collaboration [2] as part of the HITRAP project [3]. As in most experiments with trapped ions, it is necessary to reduce the temperature of the ions in order to increase the accuracy of the measurements and to diminish the magnitude of some undesirable effects such as Doppler shifts or to extend the storage time of the ions in the trap. In the SPECTRAP experiment, resistive cooling is foreseen for first experiments. Meanwhile, we are currently setting up a laser system for laser cooling of Mg^{+} ions inside the trap, with which HCI can be quickly and efficiently cooled down sympathetically.

Experimental: The laser system is composed of a 1.1 W fiber laser at 1118.54 nm and two successive second harmonic generation (SHG) ring cavities for frequency quadrupling (Fig.1). In the first SHG cavity, non-critical phase matching (NCPM) of a lithium triborate (LBO) crystal is used for doubling. The 20 mm long LBO nonlinear crystal was cut for NCPM with an optimum beam waist [4] of 28 µm. Using the ray transfer matrix analysis [5] we designed a bow tie resonator that allows us to fit the oven with the crystal kept at T = 90ºC in the middle of the short arm and to obtain the required beam waist in the crystal (see Fig. 2). The total length of the cavity is 1709 mm and has a full folding angle of 30º. The cavity length is stabilized to the laser frequency using the Hänsch-Couillaud locking scheme [6].

The second SHG cavity uses critical phase matching of a β-barium borate (BBO) crystal for doubling from 559.27 to 279.63 nm. A 7 mm long Brewster-cut BBO-crystal was used for type I CPM corresponding to an optimum beam waist of 16 µm [4]. We designed a bow-tie resonator capable of achieving a focus in the middle of the crystal with a waist of 16 µm in the vertical plane and 25 µm in the horizontal plane (see Fig. 2). The small astigmatism is introduced by the concave spherical mirrors, crystal faces and crystal axis. The full folding angle is 18.8º and the total length of the cavity is 504 mm.

Results: We obtained up to 80% coupling efficiency of the fundamental laser beam into the first cavity. With an input power level of 970 mW in front of the cavity, the maximum green output was approximately 240 mW, which is in accordance with the simulations.

For the second doubler we measured a coupling efficiency of up to 80% at resonance and we were able to obtain a power level of maximum 16.7 mW for the 279 nm radiation with an input power level of approximately 210-220 mW at 559 nm. Further efforts will be made in order to optimize the locking stability of both SHG cavities before the system will be used for the first time at SPECTRAP.

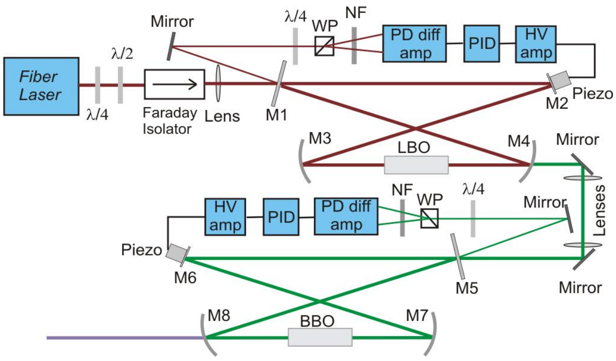

Figure 1. Schematic layout of the experiment

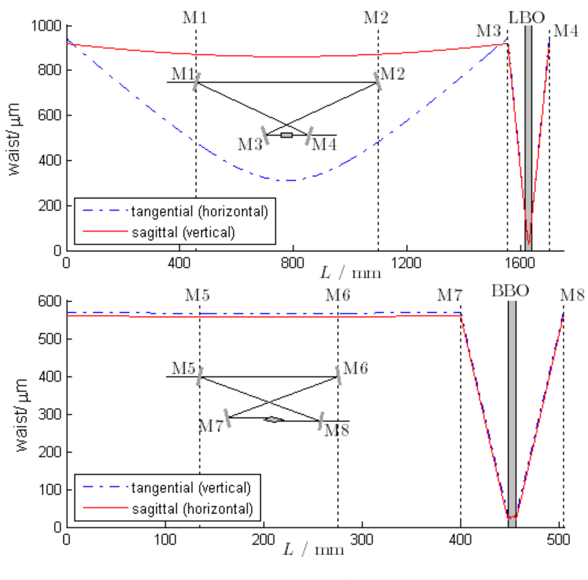

Figure 2. Beam waist inside the first (top) and the second (bottom) cavity

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