Fluoride output coupler for cavity HHG toward VUV direct state-detection of ion clocks

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Intracavity high harmonic generation (HHG) using a passive enhancement cavity has extended accessible wavelength of frequency combs, realizing precision spectroscopy in the extreme ultraviolet [1]. Lower harmonics at 150-200 nm vacuum ultraviolet (VUV) also attract interests because conventional optics based on fluoride material are still available in spite of some restrictions. In addition, rather small phase shift from the nonlinear media maintains the regular comb structures in this wavelength.

Dehmelt's proposal assumes the use of ${}^1S_0 - {}^1P_1$ transitions in alkaline-earth-like ions for state detections in the optical clock [2]. However, they all lie in VUV and the direct excitation has never been attempted. A simple estimation indicates that single-mode VUV power in the order of 10pW might yield fluorescent photons sufficient for the state detection of such ions including Al^+. Single comb components of the high-rep VUV combs may supply this level of average intensity. This approach also opens a way to simultaneous detection of multiple ions, which may overcome limited stability of the single-ion clocks. Indium ion (${}^{115}In^+$) provides an ideal test bed for this approach, where the 159 nm radiation generated as the 5th harmonic of a Ti:S laser can excite the ${}^1S_0 - {}^1P_1$ transition. In our intracavity HHG setup with the repetition rate of 110MHz, a total average intensity in the order of 10μW may provide sufficient intensity for In^+ detection, whereas it has been limited to 1.5μW in our previous report [3].

The output coupling of high harmonics from the cavity is the key to scale up the yield of intracavity HHG. Several methods were previously demonstrated using e.g. bulk sapphire windows as Brewster plates, a diffraction grating on NIR mirror, and on an anti-reflection-coated grazing incidence plate. We demonstrate an efficient output coupling method using a fluoride-multilayer-coated Brewster plate. The coupler's reflectance is designed to be >80% at 153-163 nm and >90% at 159 nm for p-polarized VUV light. The reflectivity was separately confirmed using a synchrotron radiation facility. As shown in Fig. 1, the reflectivity of ~90% was measured at 159nm as designed. The final yield of the HHG currently amounts to 4.2 μW at 159 nm, which is almost three times larger than previous work in spite of ~20% reduction of the NIR inside the cavity.

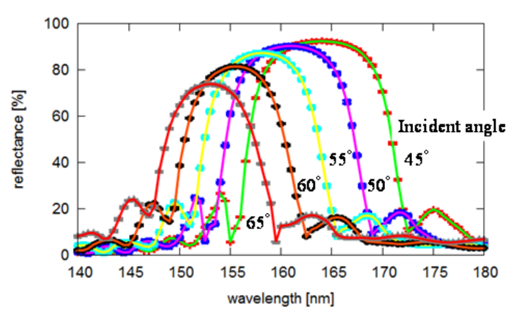

Fig. 1: Reflectivity of the fluoride output coupler.

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