Towards laser excitation of the low-energy nuclear transition in ^{229}Th

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There is strong interest in optical spectroscopy of ^{229}Th because of the unique low-energy (8.3 eV) isomer that exists in this nucleus [1]. With a transition energy in the range that is typical for resonances of the valence electrons and that is accessible for laser excitation, this nuclear resonance is attractive as the reference of an optical clock that combines high accuracy with a strong sensitivity for hypothetical effects of new physics that may be sought in frequency comparisons with atomic clocks [2]. Since direct laser excitation of the ^{229}Th nucleus has not yet been achieved, experimental studies of properties of the isomer so far have relied on its population in nuclear decay, like in the recent observation of the nuclear optical emission from ^{229}Th implanted in fluoride crystals [3].

As a step towards laser excitation of ^{229}Th we have developed a tunable vacuum-ultraviolet (VUV) laser source based on four-wave frequency mixing in xenon. Using seed radiation from two continuous-wave lasers, the system allows for precise control of the VUV frequency. Tunable in the wavelength range 149-155 nm, the source produces pulses of 6-10 ns duration with up to 40 μJ energy and is coupled via a vacuum beamline to a linear radiofrequency ion trap. In a first implementation of VUV laser spectroscopy of trapped Th^+ ions we excite three previously unknown resonance lines to electronic levels in the range of the ^{229}Th isomer energy. An analysis of the lineshape is used to estimate the linewidth of the VUV radiation to be about 6 GHz, dominated by phase noise that is enhanced in harmonic generation and in the four-wave mixing process. The use of the system in nuclear laser spectroscopy of ^{229}Th as trapped atomic ions or as dopants in calcium fluoride crystals prepared by our cooperation partners from TU Wien [4] will be discussed.

Trapping of ^{229}Th ions in charge states 1+, 2+ and 3+ has been demonstrated with the ions produced in laser ablation from solid ^{229}Th targets [5,6], but the efficiency of the method decreases substantially with increasing charge. In preparation of an optical clock with laser-cooled trapped $^{229}Th^{3+}$ ions we have developed an apparatus for the trapping of Th^{3+} recoil ions from the alpha decay of ^{233}U. The ion source in a helium buffer gas cell is linked to a linear radiofrequency trap in ultrahigh vacuum, where the ions are cooled sympathetically by laser cooled $^{88}Sr^+$ ions. $^{88}Sr^+$ has been selected as the coolant ion because of its convenient laser cooling transitions and because its charge to mass ratio is similar to that of $^{229}Th^{3+}$, so that Coulomb crystals are produced where the two ion species are closely coupled.

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