

Ideas taking shape – worldwide.

Tunable lasers at work with trapped ions

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Coulomb crystals consisting of isotopically pure Magnesium ions are built employing a new tunable continuous-wave (cw) laser light source: Mg atoms are isotope-selective ionized by resonant two-photon excitation at a wavelength of 285.3 nm. The UV laser light is generated via resonant second-harmonic generation of the output of a new cw laser C-WAVE that offers about 0.5 W single-frequency output power that is tunable in the range 450 - 650 nm. The created Mg ions are trapped and cooled, building 2D Coulomb crystals which are used for further investigation.

Tunable lasers at work with trapped ions

The group's experimental work builds on trapped ion systems and aims (i) to gain deeper insight into complex dynamics that are influenced or even driven by quantum effects, and (ii) to control individual atoms and molecules at the highest level possible to set up many-body (model) systems. Additionally, we are exploring to combine optical traps for ions and neutral atoms¹. Last year we demonstrated a sensitive high-resolution laser spectroscopy method building on quantum effects².

Common bottlenecks in all of our projects are the demanding requirements on laser systems for preparation and controlling internal and external degrees of freedom of ions. Thus our work greatly depends on innovative laser technologies that are user friendly and can be

used as versatile tools to work with a variety of atomic species, isotopes, and their combination.

The project

Topologically protected defects within Coulomb crystals can be suitable to simulate discrete solitons. During the process of crystallization, a system will seek for perfect order (minimal energy). By evolving the phase transition too fast for communication between different sections of the crystal, sub-ensembles find perfect crystalline order, while becoming incommensurate at their borders; these defects can oscillate as trapped quasi particles in their self-induced confining potential within the crystal^{3,4}.

In order to study these defects we load ten to fifty ions into our conventional RF trap via photo ionizing a thermal

beam of magnesium atoms within the trapping region. It is required to load an isotopically pure crystal from an oven that is filled with natural abundant magnesium isotopes (79% of ²⁴Mg, 10% of ²⁵Mg, and 11% of ²⁶Mg).

We can selectively load different isotopes as we ionize the atoms via a two photon process. The first step resonantly drives an electric dipole transition in the neutral magnesium, while the second non-resonant step ionizes the atoms. Due to the mass dependent frequency shift of this first transition at around 285.3 nm, we can individually address the three different isotopes⁵. By exciting the ions at around 279.6 nm we record the fluorescence light of the individual ions on a CCD camera (yielding images as shown in Fig. 1).

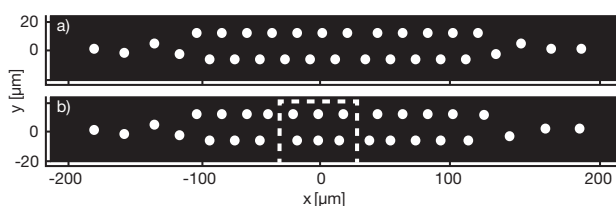


Figure 1. 1D-2D Coulomb crystals (31 ions). a) CCD image of fluorescence light of ions in zigzag configuration. b) Only the ions to the left of the centre region (dashed box) form a zigzag structure as in (a), whereas the positions on the right are mirrored along the x-axis.

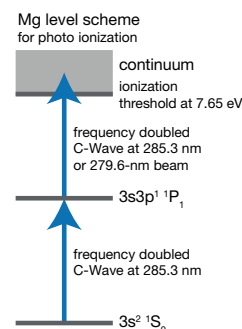


Figure 2. Schematic level scheme of magnesium. Indicated are the two photo ionization steps performed by the frequency-doubled C-WAVE light at 285.3 nm. Crucial is the first resonant excitation step: it enables the isotope selective loading of ions.

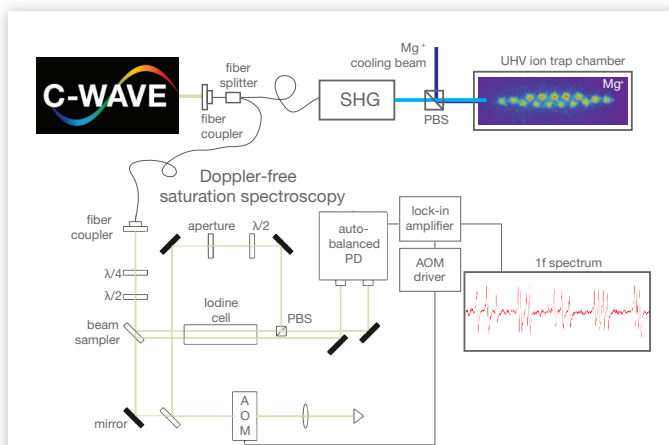


Figure 3. The setup: The C-WAVE output is fiber coupled and split for a second-harmonic generation (SHG) stage and for absolute frequency reference into a spectroscopy setup. With the frequency doubled into the UV, the C-WAVE light ionizes magnesium atoms, while the second beam cools the magnesium ions in the UHV ion trap chamber. Fluorescence light of the ions is detected with a ccd camera. Doppler-free spectroscopy (bottom): The pump beam partially transmitted at the beam sampler is double-passed through an acousto-optical modulator (AOM; center frequency 80 MHz), the center frequency is modulated by ≈ 1 MHz at a rate of 10 kHz for 1f-lock-in detection.

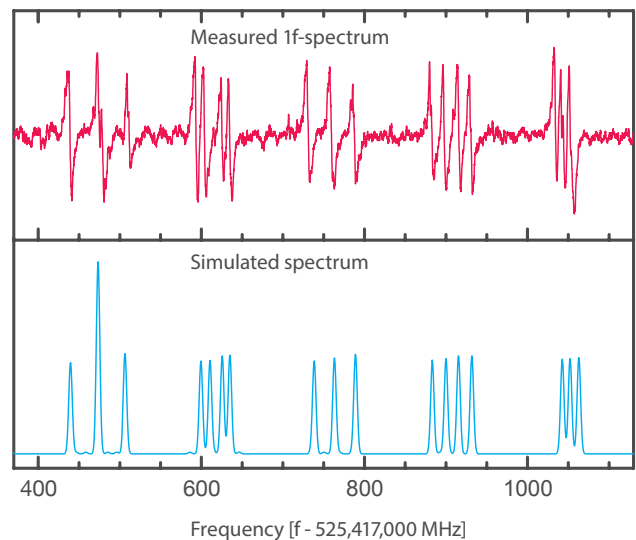


Figure 4. Iodine spectrum in the frequency range 525,417,400 MHz to 525,418,100 MHz. About 10 mW of the 570.6 nm light is sent to the Doppler-free saturation spectroscopy setup. The figure compares the recorded 1f-spectrum with a calculated spectrum.

Utilizing the C-WAVE

In the present experiment the C-WAVE system is used for the photoionization step. Light at 570.6 nm is fibre coupled (coupling efficiency greater than 70 %) and sent to a homebuilt second-harmonic generation (SHG) external ring cavity using a BBO crystal to convert the VIS to the UV (285.3 nm), see Fig. 3. The UV output beam (a few mW) of the SHG stage is superimposed with a second UV beam at 279.6 nm (generated by a different laser system). Both are guided free-space to an ultra-high-vacuum chamber where the trap is mounted.

The beams are collimated with the central trapping region. Here the first beam ionizes the neutral magnesium atoms

while the second Doppler cools the trapped ions into a crystalline structure. The ions are trapped in a combined rf and dc confinement potential. To ensure the isotopically enhanced ion loading, a fraction of the C-WAVE output light is sent to an Iodine Doppler-free saturation spectroscopy setup, see part of Fig. 3. This setup is used as an absolute frequency reference and enables accurate tuning of the C-WAVE.

A recorded 1f spectrum around 570.6 nm is shown in Fig. 4 and agrees within a few MHz with a simulated spectrum⁶.

The C-WAVE system is fully integrated into our experiment with trapped ions. Due to its wide tuning range from

450-650 nm, its demonstrated narrow linewidth < 1 MHz, and the high output in the 0.5 W range, C-WAVE is a flexible CW laser light source, well suited for various applications in spectroscopy and quantum optic experiments.

For additional information on the subject please feel free to contact [Dr. Ulrich Warring, Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Freiburg, Germany, ulrich.warring@physik.uni-freiburg.de](mailto:Ulrich.Warring@physik.uni-freiburg.de), or [Dr. Niklas Waasem, Hübner GmbH & Co. KG, Kassel, Germany, niklas.waasem@hubner-photonics.com](mailto:Niklas.Waasem@hubner-photonics.com)

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