Search for efficient laser resonance ionization schemes for Ta and W in KISS

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In KISS (KEK Isotope Separation System) [1)], laser resonance ionization is employed for the element-selective ionization of multi-nucleon transfer reaction products. We searched for efficient laser resonance ionization schemes for tantalum (Z = 73) and tungsten (Z = 74), which are the elements that are studied in KISS.

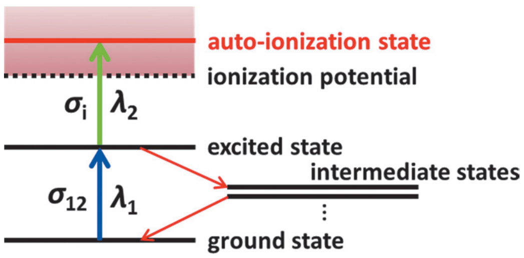

Fig. 1 Two-color laser resonance ionization

Fig. 1 shows a schematic view of two-color laser resonance ionization. An atom is element-selectively excited by the first step laser with a wavelength of λ_1. Through the second step laser with a wavelength of λ_2, the atom then transits from the excited state to an auto-ionization state (AIS), which is located above the ionization potential. The AISs having ionization efficiencies that higher than that by means of the continuum by more than ten times are searched for in general. [2)]

We used wavelength-tunable dye lasers pumped by excimer lasers to obtain laser beams of $2\lambda_1$ and λ_2. The wavelength λ_1 in the ultraviolet ray region is generated from the $2\lambda_1$ wavelength by using a second harmonic generator, which consists of a non-linear crystal of BBO. Both lasers are transported into a reference cell that was newly made to search for ionization schemes in off-line experiments. The lasers were focused on a spot of a few mm^2 between ion-acceleration electrodes. Neutral atoms were evaporated from a filament and ionized by laser irradiation between the electrodes. Ions were accelerated by the electrodes and detected by a channeltron at about 30 cm away from the ionization region. The ions were mass-analyzed by measuring the TOF. The mass resolving power was measured to be 12.3%.

We scanned λ_2 to search for AISs; then, we measured laser-ionized atoms by means of the AIS by changing the power of the respective lasers. The λ_1s were selected from the known excited states that had a high Einstein A coefficient.[3)] We deduced the photon absorption cross section (σ_{12}, σ_i) of each transition by fitting the solution from rate equations[2, 4)] to the laser power dependence of ion counts. The rate equations express the time evolution of the number of atoms in the ground state, the excited state, and the AIS. In addition to those states, we considered the intermediate states, where the atoms decay from the excited state, and are located above the ground state. The excitation rate (ionization rate) is proportional to the photon absorption cross section of the transition from the ground state (the excited state) to the excited state (the AIS). These rates are also proportional to the photon densities of the λ_1 laser and λ_2 laser. We deduced the laser powers required for the saturation conditions of ionization probability in the KISS gas cell from the determined photon absorption cross sections.

For tantalum, λ_2 was scanned from 410 to 425 nm with λ_1 = 264.8258 nm, so that four strong peaks were observed. The strongest peak at 421.652 nm yielded $\sigma_{12} = 4.8 \pm 0.5$ (stat.) $\pm$ 1.0 (syst.) $\times 10^{-15}$ cm^2, $\sigma_i = 2.0 \pm 0.2$ (stat.) $\pm$ 0.8 (syst.) $\times 10^{-16}$ cm^2. The laser powers required for the overlap in the gas-cell (φ10 mm) were $P_1 \sim 0.5$ mJ/pulse, $P_2 \sim 29.3$ mJ/pulse. On the other hand, for tungsten, λ_2 was scanned from 404 to 414 nm with λ_1 = 245.2737 nm, so that two strong peaks were observed. The stronger peak at 404.393 nm yielded $\sigma_{12} = 4.5 \pm 0.6$ (stat.) $\pm$ 0.6 (syst.) $\times 10^{-16}$ cm^2, σ_i = 7.5 $\pm$ 0.7 (stat.) $\pm$ 1.6 (syst.) $\times 10^{-17}$ cm^2. The laser powers required for the overlap in the gas-cell (φ10 mm) were $P_1 \sim$ 5.5 mJ/pulse, $P_2 \sim$ 241.9 mJ/pulse. These powers required are too high for our laser system to achieve saturation. In our laser system, the maximum laser power is approximately 200 μJ for the first step laser and about 2 mJ for the second step laser. The ionization probability achieved using our laser system is expected to be as low as 11% for tantalum and 0.33% for tungsten. We will search for other λ_2 values in different wavelength regions with the current λ_1 and also look for AISs with different λ_1 values.

The resonance structure of the AIS might be affected by the isotope shift of the wavelength. We are going to increase the mass resolving power of the reference cell by introducing electric lenses and a longer flight tube, which will provide us with further information on the AIS.

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