

Production of singly charged Sn ions by charge exchange in H₂ gas

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The evolution of charge-state-resolved kinetic energy spectra of Sn ions ejected from a laser-produced plasma (LPP) of Sn as a function of the density of the H₂ buffer gas surrounding the LPP is investigated. Without a H₂ buffer gas, energetic 1 - 5 keV Sn ions in charge states of 4+ up to 8+ are detected. In this keV regime, lower Sn charge states, i.e., below 4+ are absent. When H₂ is introduced into the system, low-charged energetic Sn ions can be produced by a series of consecutive electron capture processes. However, as electron capture by Sn²⁺ ions from H₂ is endothermic, no significant population of singly charged Sn ions is expected in the keV regime. At H₂ pressures of 6x10⁻⁴ mbar and higher, however, we only detect Sn²⁺ and Sn⁺ ions.

To explain the production of keV Sn⁺ ions, electron capture by metastable Sn^{2+*} ions has been proposed [1]. Semi-classical calculations on Sn³⁺-H₂ collisions [2] indicate that one-electron capture by Sn³⁺ ions populates Sn²⁺ ions in metastable states. Model simulations (using theoretical 2-state Landau-Zener cross sections to account for capture by each of the three metastable ³P_J levels) to track the charge states of Sn ions while traversing the H₂ gas agree with our measured data. This underpins the key role of metastable Sn^{2+*} ions as a gateway to the production of Sn⁺ ions. From an LPP-based EUV source perspective, the production of energetic Sn⁺ ions in the buffer gas is of high relevance, as it shifts the charge state balance from Sn²⁺ towards Sn⁺ ions, which have a larger stopping cross section than Sn²⁺ ions [3].

[1] Rai et al., 2023 to appear in Plasma Sources Sci. Techn.

[2] Rai et al., 2022, Phys. Rev. A. **106**, 012804

[3] Abramenko et al., 2018, Appl. Phys. Lett. **112**, 164102

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