Operation of a Reactive Magnetron Sputtering Ion Source using Water Vapor Plasma

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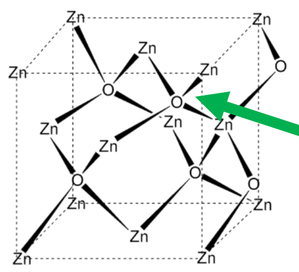
Water Vapor Plasma

- has widely been used in:
  - Surface modification
  - Functional film deposition of oxides, as a substitute for conventional O_2 gas in TiO_2, In_2O_3, and **ZnO.**
- By extracting from an ion source, low energy deposition of nanoparticles with minimal damage to sensitive surfaces can be achieved

ZnO Lattice



The water molecule and its rotational and vibrational states

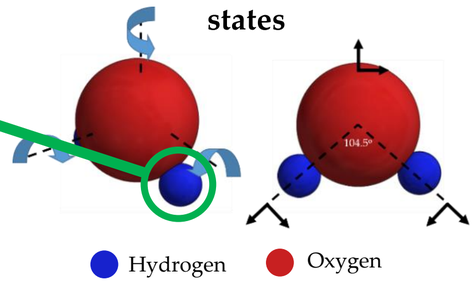
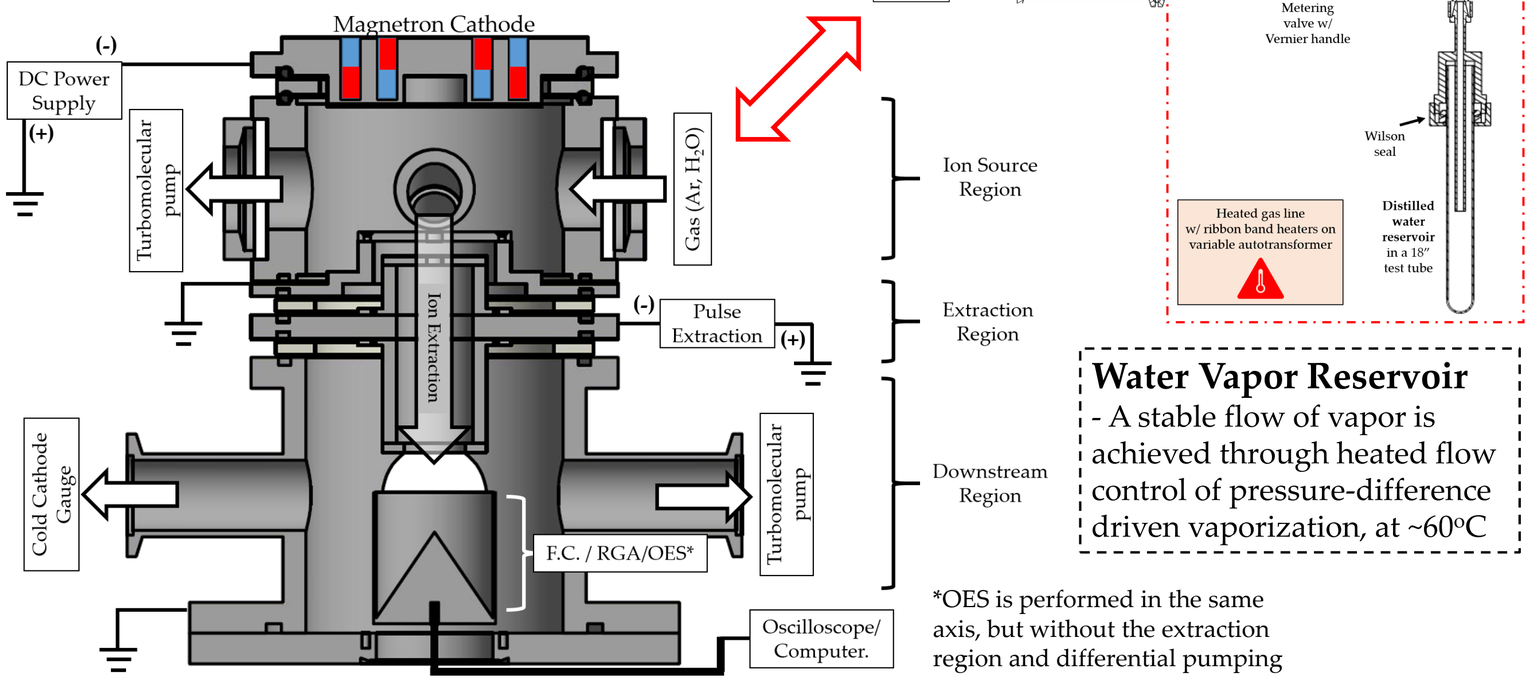


Image Reference [1]

Effect of H_2O to ZnO:
- Increased conductivity through shallow donor doping.
- Lattice stress relaxation

DC Reactive Magnetron Sputtering Ion Source

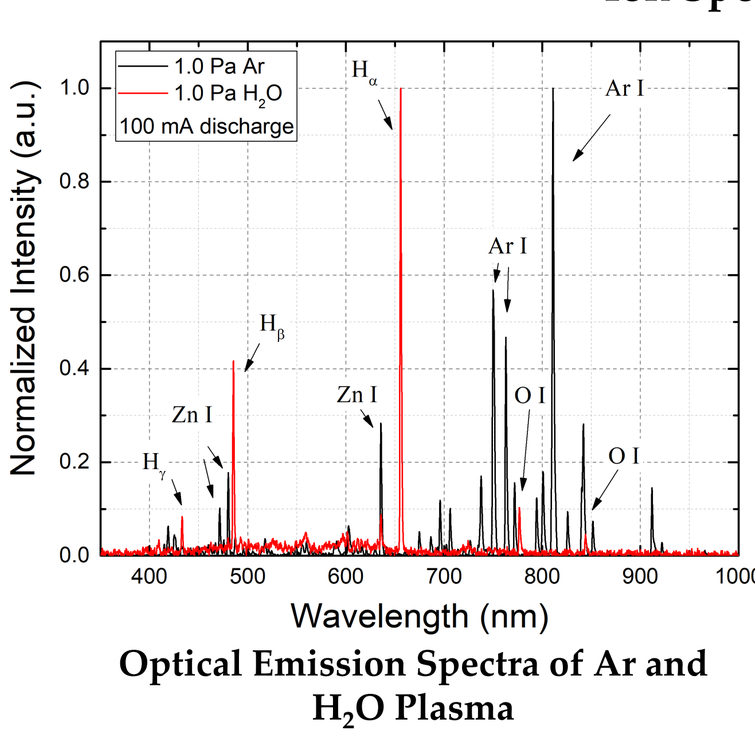


Water Vapor Reservoir
- A stable flow of vapor is achieved through heated flow control of pressure-difference driven vaporization, at ~60°C

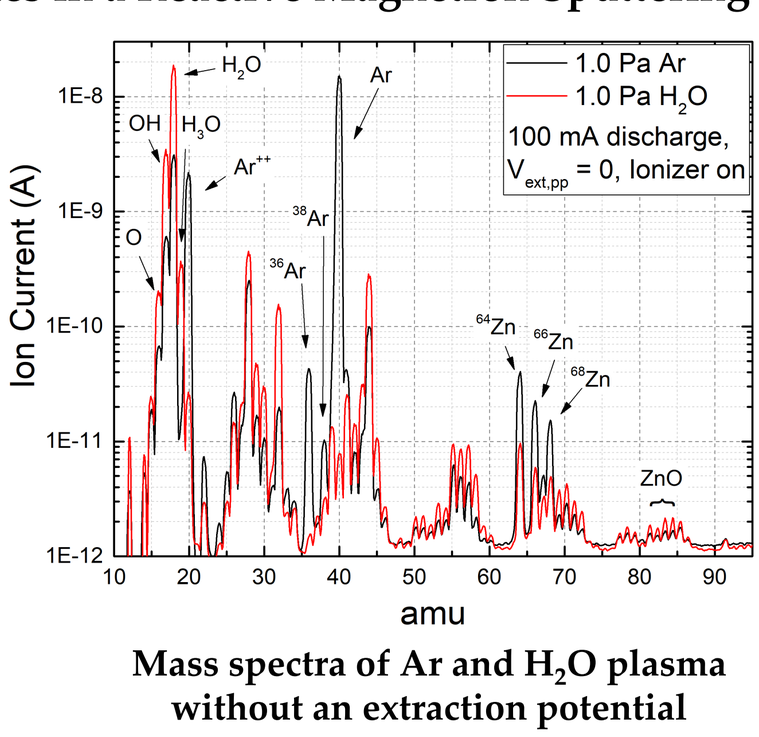
*OES is performed in the same axis, but without the extraction region and differential pumping

- The system utilizes a 70-mm ϕ Zn (99.2%) metal target with a toroidal magnetron configuration
- The extraction region is 40.0 mm away from the target and has a 2.0-mm aperture grounded aperture, spaced 4.8-mm from the extraction conduit, which has a total length of 72.0 mm.
- With a grounded ion source, pulsed extraction is done using a high speed amplifier (NF 4020) with $V_{ext,pp}$ = -100V, from 1KHz to 500KHz

Ion Species in a Reactive Magnetron Sputtering Ion Source



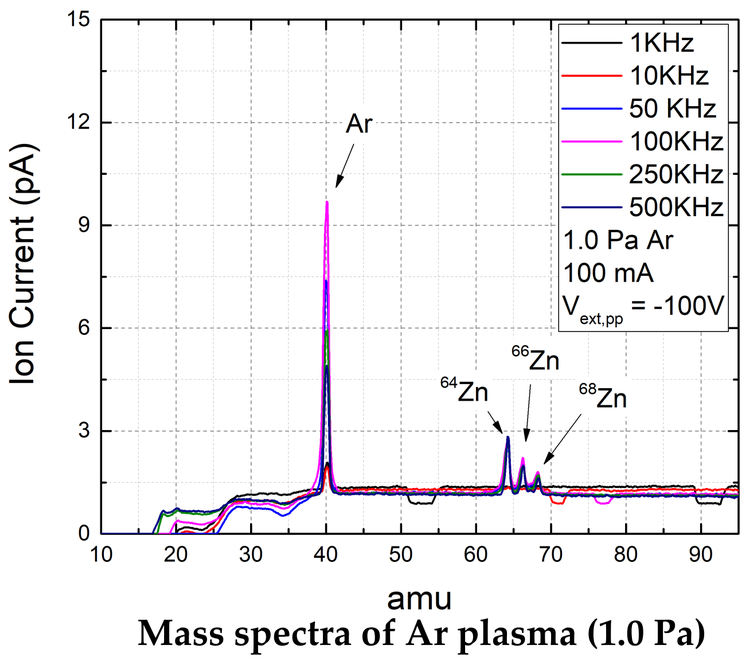
Optical Emission Spectra of Ar and H_2O Plasma



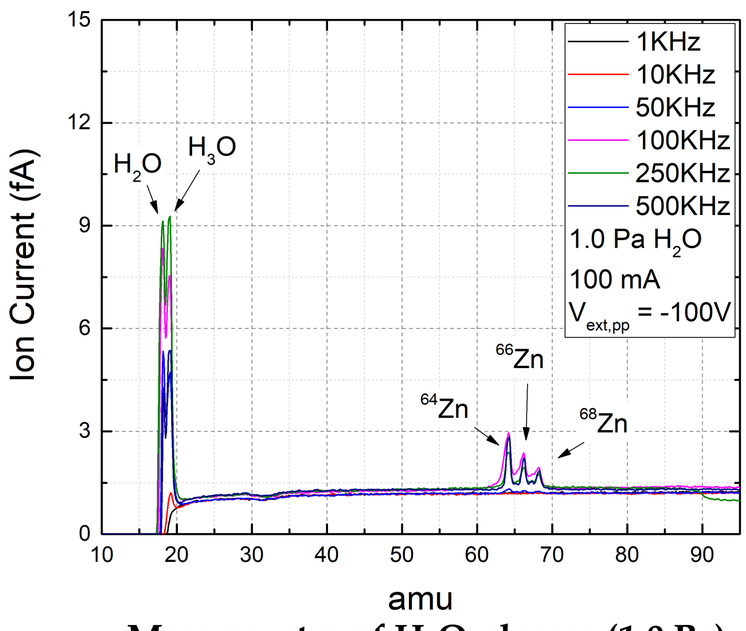
Mass spectra of Ar and H_2O plasma without an extraction potential

- The optical emission spectra was first measured in the ion source to confirm the introduction of water vapor.
- From the spectra, the peak intensity of O I is considerably lower than that of Hα and Zn I.
- The mass spectra of the Ar and H_2O plasma were measured using a quadrupole mass analyzer (SRS RGA100) with a filament ionizer in the differentially pumped downstream region, without a pulsed extraction potential
- Zn and ZnO neutrals were transported from the ion source when Ar and H_2O plasma were used.
- For water vapor plasma, the ratio of O I (777nm) to Hα is 0.103 while the OH to H_2O intensity is 0.184

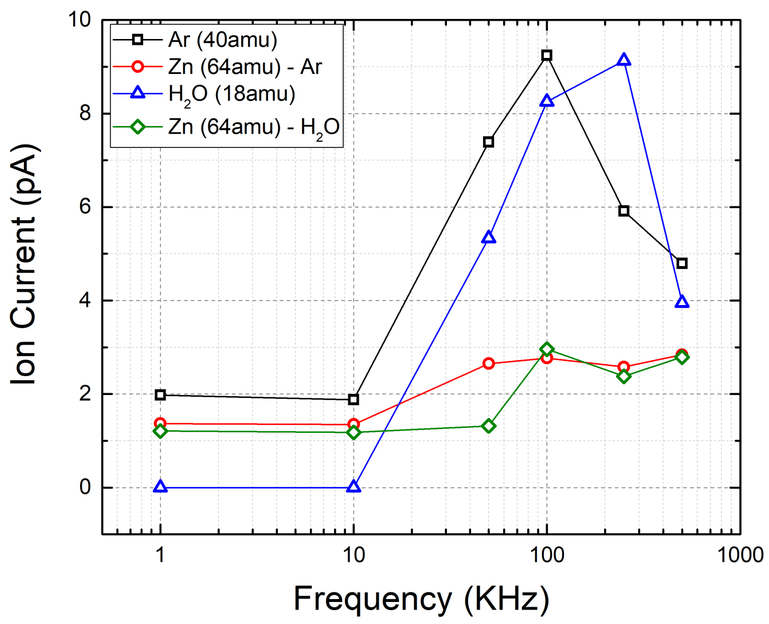
Pulsed Ion Extraction from a DC Reactive Magnetron Sputter Ion Source



Mass spectra of Ar plasma (1.0 Pa)



Mass spectra of H_2O plasma (1.0 Pa)



Variation of ion peak current

- Extraction was measured using the QMA without the filament ionizer, to measure and identify the ion species extracted from the ion source.
- For Ar plasma, the species detected were Ar (40amu) and Zn (64,66,68 amu), while for H_2O plasma, it were H_2O (18amu), H_3O (19amu) and Zn (64,66,68amu). ZnO was not observed in the H_2O plasma.
- The discharge ion peak intensity increased as the extraction frequency increased, with a maximum peak signal observed at 100KHz for Ar and 250KHz for H_2O. After the maximum, a decrease in the intensity was observed
- The Zn ion peaks were only observed at 50KHz and 100KHz for Ar and H_2O plasma, respectively. The ion current did not increase as the frequency was further increased.

Main References:

[1] C.G. Van De Walle: Hydrogen as a cause of doping in zinc oxide, Physical Review Letters, 85 (2000), 1012–1015.

[2] Vasquez, M.R., Ilasin, M.D., Pengson, L.T.O., Ramos, M.K., Cuevas, A.G: Extraction and transport of low-energy Ar ion beams with a broad cross-section, Vacuum 187 (2021), 1-7

[3] Kawamura, Y., Hattori, N., Miyatake, N., Uraoka, Y.: Comparison between ZnO films grown by plasma-assisted atomic layer deposition using H_2O plasma and O_2 plasma as oxidant

[Image Reference 1] Image taken from: https://www.acs.org/content/acs/en/molecule-of-the-week/archive/z/zinc-oxide.html