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Influence of helium on deuterium content in W-D-He co-deposited layers

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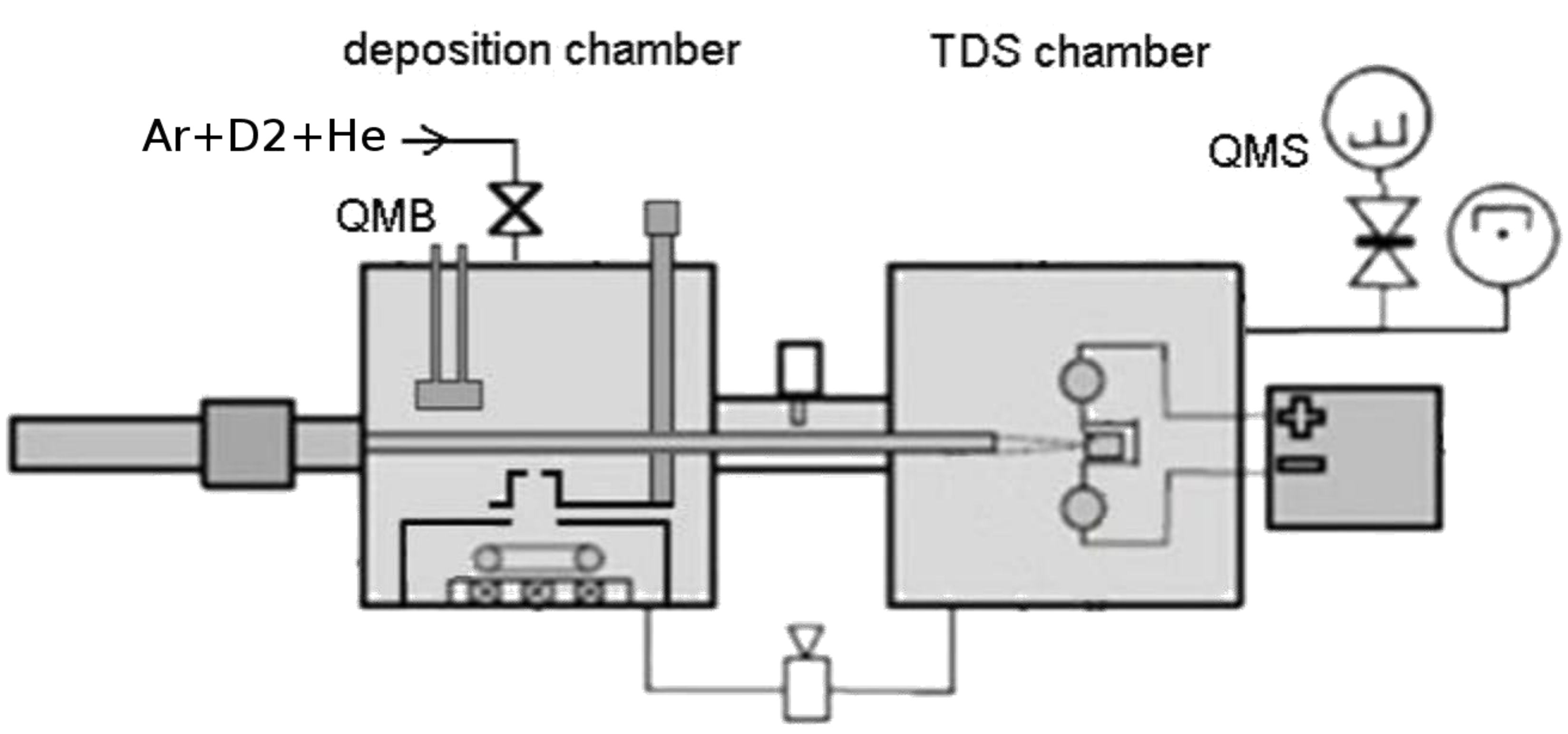
1. INTRODUCTION

- Co-deposition is one of the main channels for hydrogen accumulation in fusion devices.
- He will be present in fusion device as a product of D-T reaction
- Presence of He can affect structure of co-deposited layers, hydrogen accumulation in them
- Separating ^{4}He and D_2 represents technical challenge.

2. EXPERIMENTAL

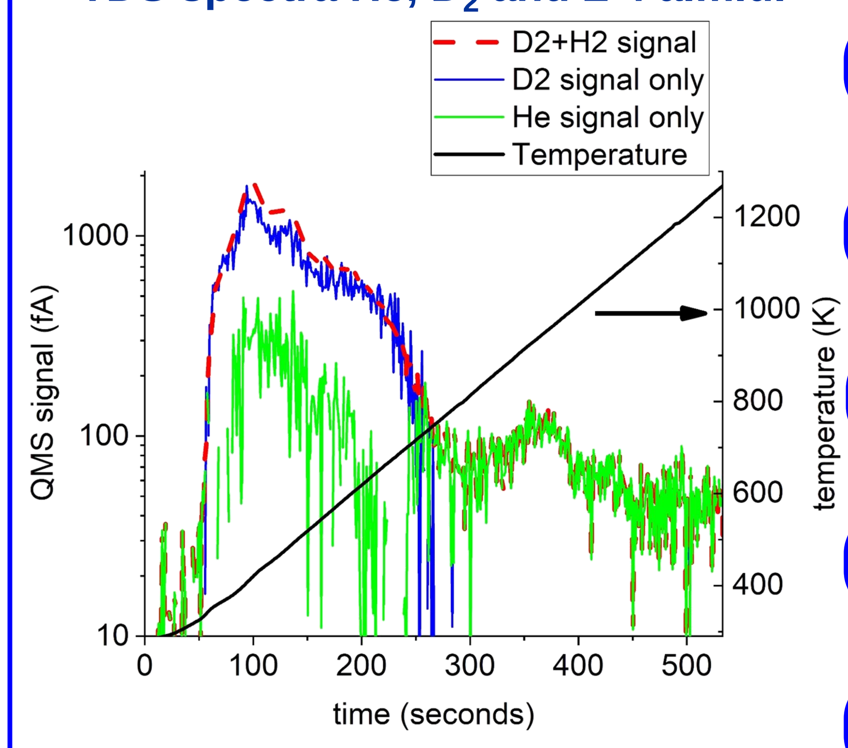
2.1. MD-2 INSTALLATION [1]



- Two separately pumped chambers:
  - Deposition P~2×10^{-5} Pa
  - Thermal desorption spectroscopy P<5×10^{-7} Pa
- Magnetron sputtering of W (99.998% purity)
- Ar-D_2-He plasma. $P_{Ar}=P_{D2}$=2.8 Pa, P_{He}=0-20% P_{D2}
- Control experiments with pure Ar-D_2 and Ar-He plasma
- Film thickness ~ 100 nm, Quartz microbalance monitored; deposition rate ~ 2 Å/s
- Controlled substrate temperature, T=RT-800K,
- 50 K substrate temperature steps
- In-vacuo TDS analysis up to 1250 K, 2 K/s ramp-up rate
- Separation of He and D2 TDS fluxes by means of two quadrupole mass-spectrometers (QMS)

2.2. TDS ANALYSIS. He and D_2 flux separation

TDS spectra He, D_2 and Σ 4 a.m.u.



D_2 and He separation algorithm

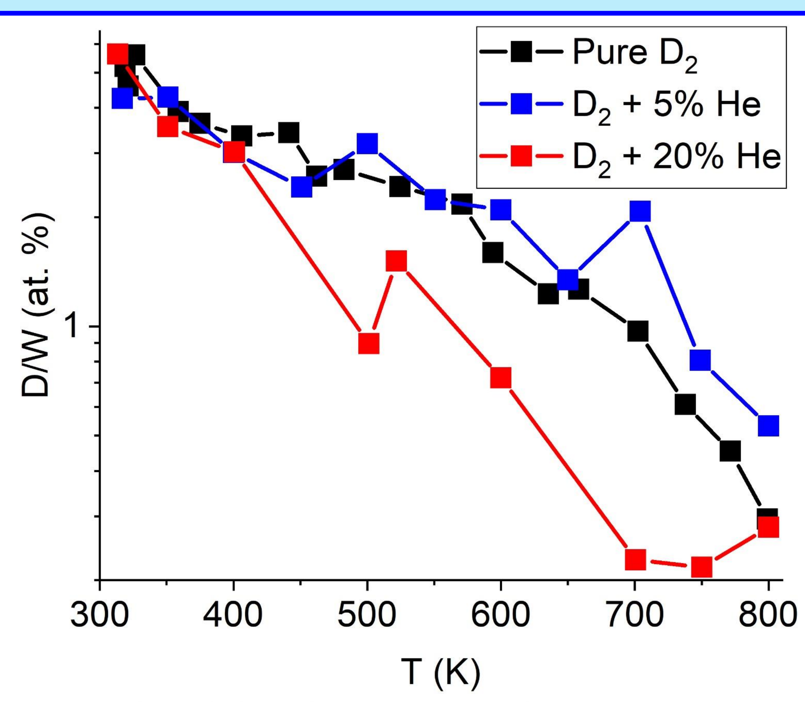
1. Measure D_2 and He absolute sensitivities for both QMS as functions of signal currents
2. Calculate D_2 particle flux using QMS with 19 eV ionization energy 4 a.m.u. current signal and calibration
3. Calculate D_2 current signal for QMS with 70 eV ionization energy and reverse D_2 calibration coefficient
4. Subtract D_2 current signal from total 4 a.m.u. current signal for QMS with 70 eV ionization energy
5. Calculate He particle flux using he only current signal and calibration

- Two Extorr 100M QMS with different electron ionization energy settings were used to separate D_2 and He :
- 70 eV ionization energy in Faraday cup mode to measure combined D_2 and He signals
- 19 eV ionization energy in electron multiplier mode to measure D_2 flux only
- Both QMS absolute sensitivite repeatedly calibrated for H_2, D_2, He and Ar absolute sensitivities using procedure from [1,2]. HD sensitivity was taken as a geometric mean of H_2 and D_2 sensitivities
- D content calculated using both 4 a.m.u. and 3 a.m.u. signals. 3 a.m.u. signal taken from Faraday cup QMS
- For 20% He + D_2 experiments, 20 point rolling average smoothing applied to the signal due to signal noise

3. EXPERIMENTAL RESULTS

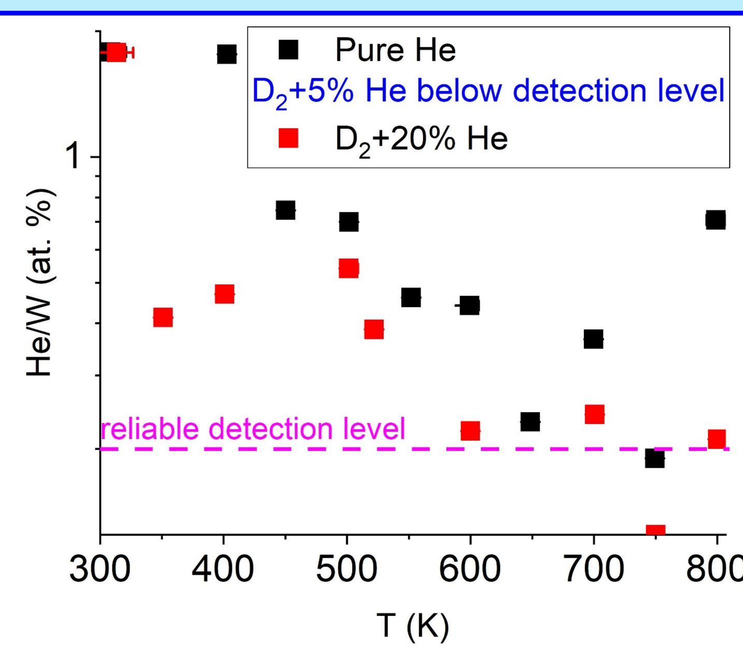
3.1. TOTAL D2 and He CONTENTS

3.1.1. TOTAL D_2 CONTENT



- **5% He/D** slightly **increases D/W**
- **20% He/D decreases D/W**
- At **T = 800 K D/W ≥ 0.3 at. %** in all experiments
- With He presence, D/W does not decrease monotonously with T. Changes in film structure are a likely explanation

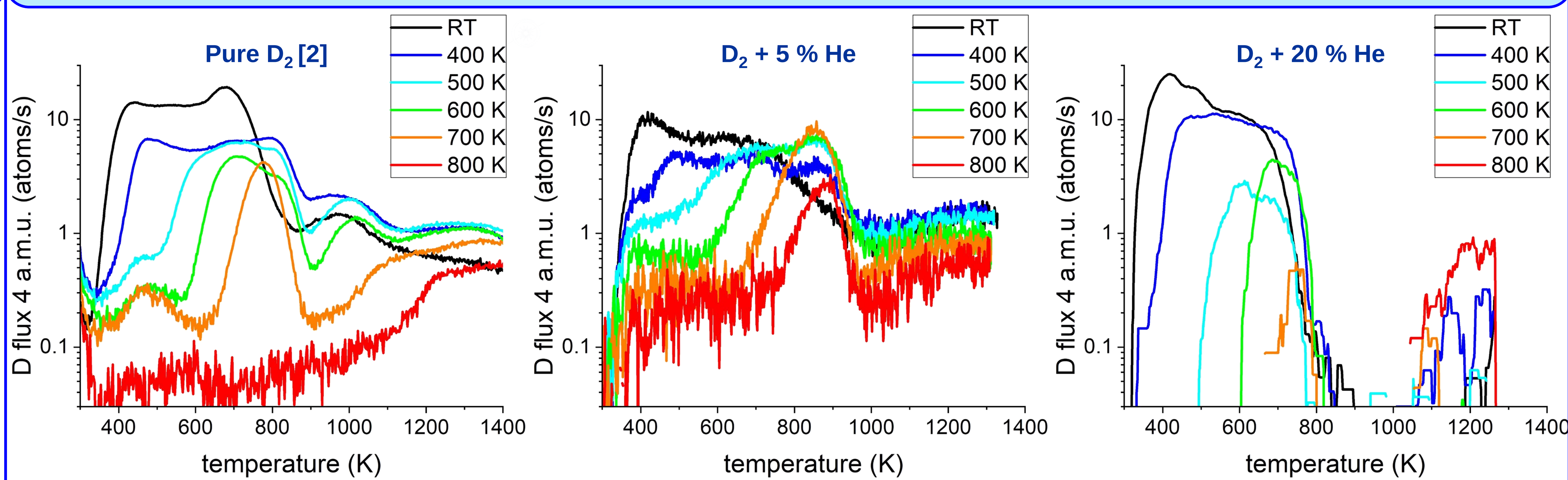
3.1.2. TOTAL He CONTENT



- **He/W below detection range for 5% He/D**
- **He/W ↑ at T=800K → He bubble formation** is a possible explanation
- He/W comparable with D/W, even with He/D=20%

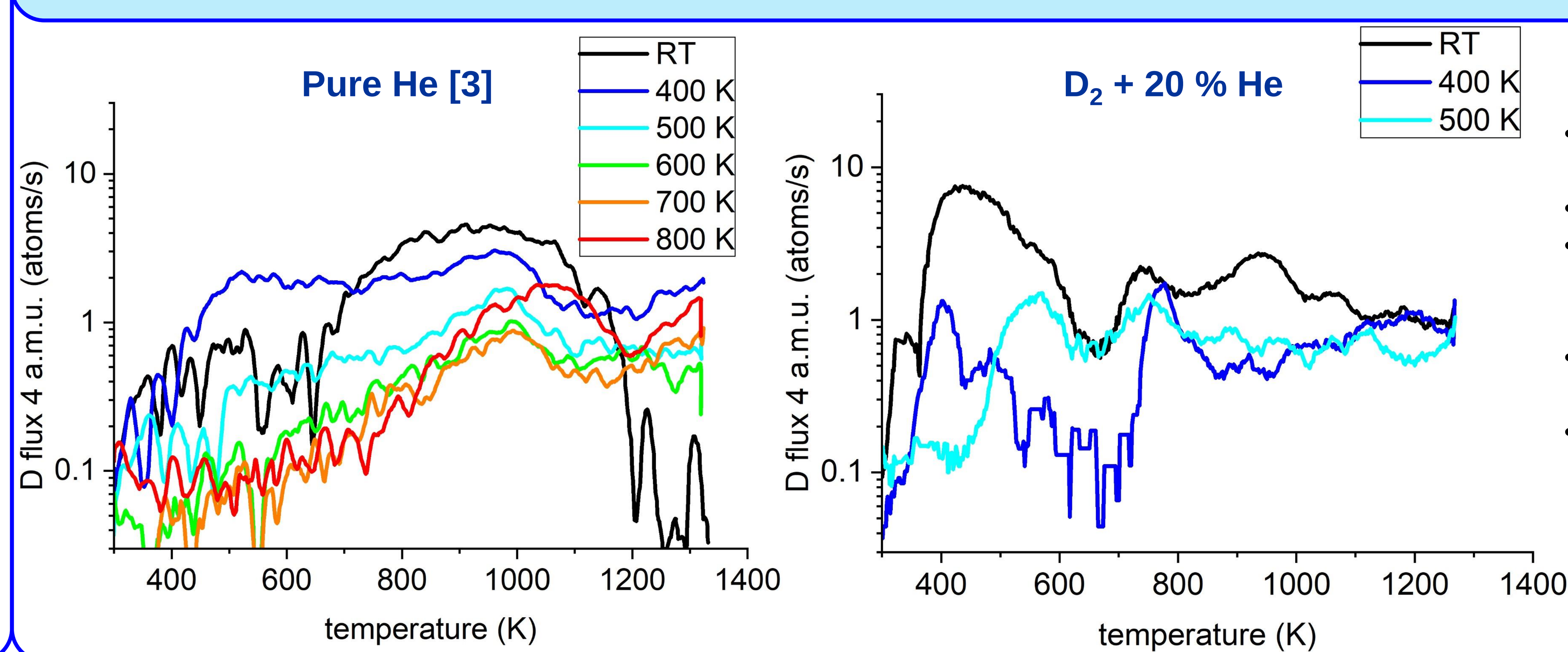
3.2. TDS ANALYSES

3.2.1. DEUTERIUM TDS SPECTRA



- Similar peak structures fin all experiments. Main D_2 **desorption at T < 900 K**
- Most D released at **T<900 K**
- Adding **5-20% He** suppresses D_2 desorption for **900 K < T < 1100 K**
- For **He/D>0, D_2 desorption** at high T **increases** with deposition T:
  - peak at **800-900 K** for **He/D = 5%**
  - peak at **700-800 K** for **He/D = 20%**

3.2.1. HELIUM TDS SPECTRA



- D_2+20% He spectra at T≥600 K not shown due to high noise level
- Broad desorption spectra from 400 K to 1200 K
- He accumulation associated with desorption at ~ 600-800 K possibly competitive with D2 accumulation
- For pure He/W layers a pronounced increase of He accumulation is obversved at $T_{deposition}$ = 800 K
- All He spectra resemble data for He ion implantation experiments [4]. Data for 20% He experiments closer to ion implantation spectra after atmospheric exposure.

4. CONCLUSIONS

- In general, **5% He increases D2 content** in co-deposited layers, while **20% He decreases D2 content.**
- **Significant D content** (**D/W ≥ 0.3 at. %**) can be observed at highest **$T_{deposition}$ = 800 K. D/W=0.5 at. %** for **5% He.**
- **Deuterium content vs. deposition temperature** curves are **non-monotonous** when He is present
- Adding **5-20% He suppresses D2 desorption at high temperatures**, possibly due to **D_2 and He competition** for the **same trapping sites**
- **20% He** is enough for the **He desorption spectra** to **resemble** data for **pure He/W co-deposition and ion implantation** experiments. It's likely that **20% He** significantly **affects film's structure**.

5. FUTURE PLANS (IN THE WORKS)

- Study co-deposits with 10 and 15 % He gas mixture content
- Study co-deposited film structures in order to explain the observed effects (He bubble formation, etc).

6. REFERENCES

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[3] S. Krat, E. Fefelova, A. Prishvitsyn, Y. Vasina, Z. Harutyunyan, Y. Gasparyan, et al., Helium accumulation in tungsten layers deposited in Ar-He magnetron discharge, J. Phys. Conf. Ser. 1686 (2020) 012020. doi:10.1088/1742-6596/1686/1/012020.

[4] Y. Gasparyan, S. Ryabtsev, V. Efimov, Z. Harutyunyan, A. Aksenova, A. Poskakalov, et al., Helium retention in tungsten under plasma and ion beam irradiation and its impact on surface morphology, Phys. Scr. T171 (2020) 014017. doi:10.1088/1402-4896/ab4068.

7. Acknowledgements

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