Quantifying Nuclear Reactions in Metal Hydrides at Low Energies

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Exploratory Topics 2022: Lawrence Berkeley National Laboratory

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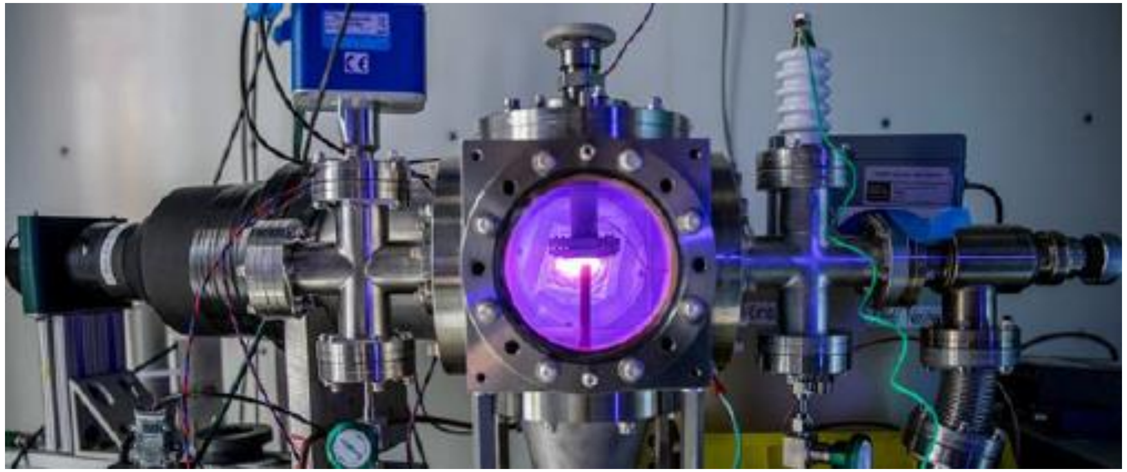

Project title:
Quantifying Nuclear Reactions in Metal Hydrides at Low Energies

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Project outcomes:
Identify metal hydride loading and excitation conditions that affect deuterium-deuterium fusion reaction rates below 500 eV.

Key takeaway: By quantifying nuclear reaction rates for a series of well-defined loading and excitation conditions we can discover parameters for reaction rate scaling in metal hydrides.

Hypothesis

- Our hypothesis is that we can quantify dd-fusion (and other nuclear reactions) in metal hydrides for a series of deuterium loading and excitation conditions using a suite of detectors
- Specifically we are working with
  - Palladium foils (COTS and artesian)
  - Deuterium loading with electrochemistry and/or a low energy deuterium ion beam
  - In situ detectors for
    - energetic neutrons (EJ 309 + PMT)
    - ions (silicon diodes, scintillators, CR-39)
    - x-rays (might as well add an Amptek x-ray detector)
    - low energy neutrals atoms/molecules and ions with a quadrupole mass spectrometer (RGA)
  - Reaction excitation, deuterium loading and vacancy production with deuterium ions (<500 +/-10 eV)
  - Reaction excitation with laser driven plasmon resonances in nano-porous Pd
- We build experiments of increasing complexity in a modular approach:

  1. with el-chem: events vs. el-chem conditions (time, drive current, and bias)

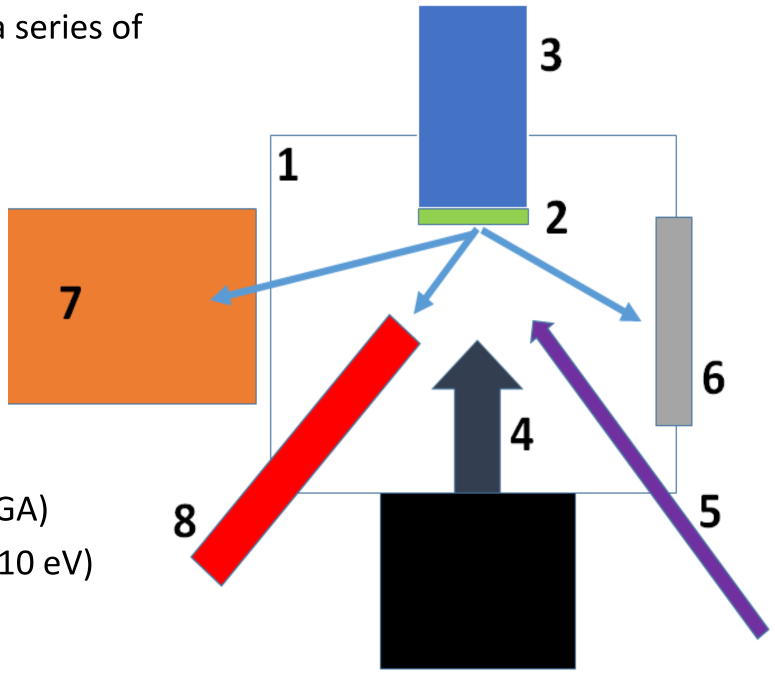
  3. with ion beam: events vs. beam conditions (time, fluence, current ~1 to 10 +/-0.02 mA, beam spot ~few cm^2)

  4. with el-chem loading and ion beam

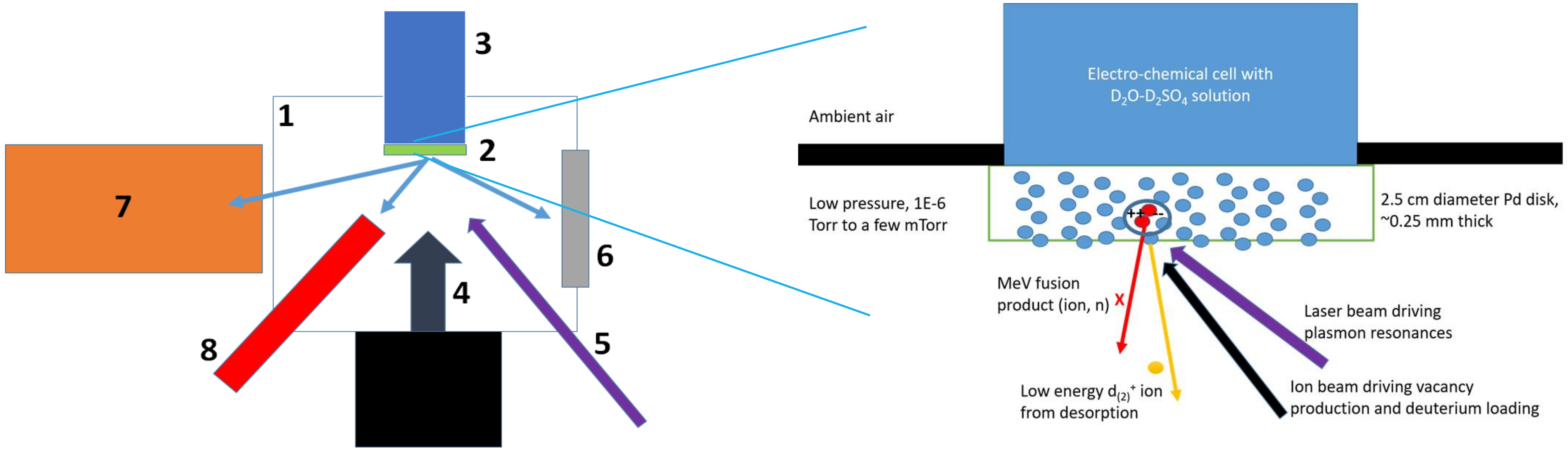
  5. el-chem and laser plasmons, then also with the ion beam

  6. repeat for a series of starting materials

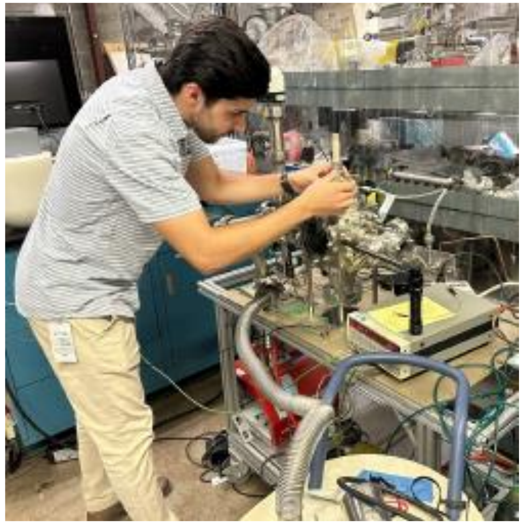
  7. ex situ analysis of Pd for transmutation and nuclear reaction products and ex situ tritium counting



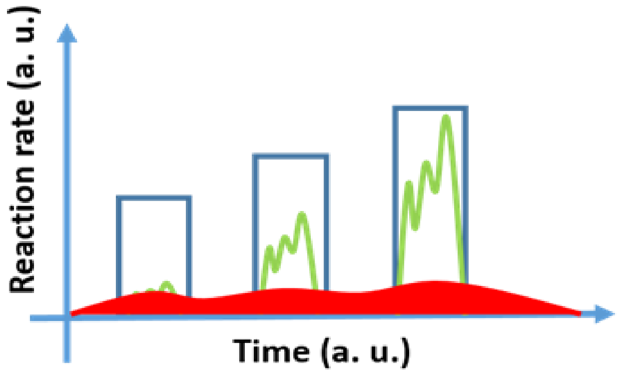
Experimental Setup



1. Vacuum chamber, a 6” cube
2. Pd foil
3. El-chem cell (co. C. Berlinguette)
4. Deuterium ion source and beam
5. Laser for plasmon excitation
6. Ion detector(s)
7. Neutron detector(s)
8. Quadrupole mass spectrometer



Berkeley Lab setup with UC Davis (Prof. J. Munday) grad student Micah Karahadian inspecting the el-chem cell



- Notional results plot with nuclear event rate changing over time and for a series of loading and excitation conditions

Data Acquisition

Measurement	Recording Method	Settings	Latency	Storage Media
Pressure	COTS pressure gauge with computer control	Base ~1E-6 Torr range, up to mTorr during el-chem runs (tbd)	Seconds to hours (does not have to be not read out all the time)	Hard drive and cloud storage
Partial pressures, surface desorption	Residual gas analyzer (RGA), ion counting mode (optional) with computer control	Optional differential pumping	< a few ms	Hard drive and cloud storage
Neutron rate	3-He based areal monitor, EJ 309/PMT with readout picoscope	Standard	<a few ms	Hard drive and cloud storage
MeV ion rate	Silicon based diodes and optional scintillator plus PMT, picoscope (digital oscilloscope) to computer	Standard reverse biased diode	< a few ms	Hard drive and cloud storage
Surface desorption rate	RGA mass spectrometer with USB to control computer	Partial pressure vs. time, ion counting mode	<a few ms	Hard drive and cloud storage
El-chem settings	El-chem controller with USB to control computer	Current (~0-0.5 A), voltage (~0 to 1 V)	< a few ms	Hard drive and cloud storage
Laser and spectrometer	Instrument integrated computer controls	Laser power, spectrometer resolution (TBD)	< a few ms	Hard drive and cloud storage

- DAQ reference: M. Ayllon Unzueta, et al., Arun Persaud, “An all-digital associated particle imaging system for the 3D determination of isotopic distributions”, *Rev. Sci. Instrum.* 92, 063305 (2021), https://doi.org/10.1063/5.0030499

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CHANGING WHAT'S POSSIBLE

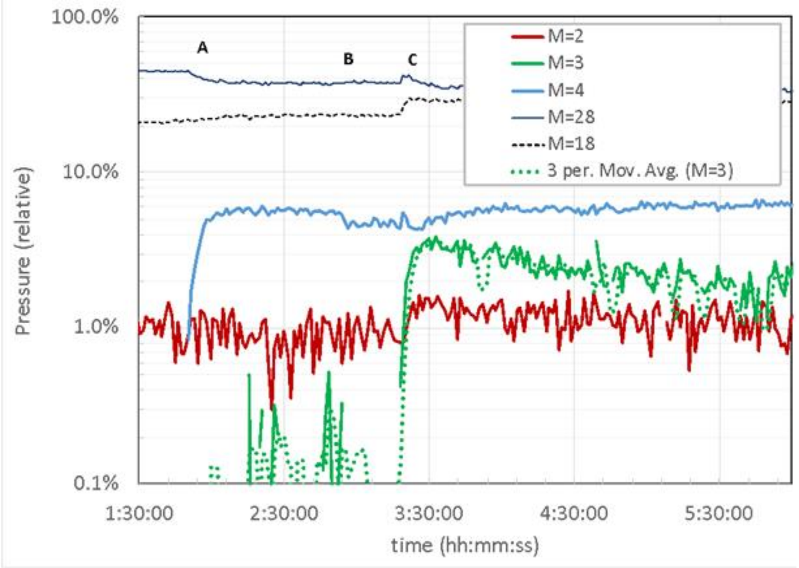
Modeling

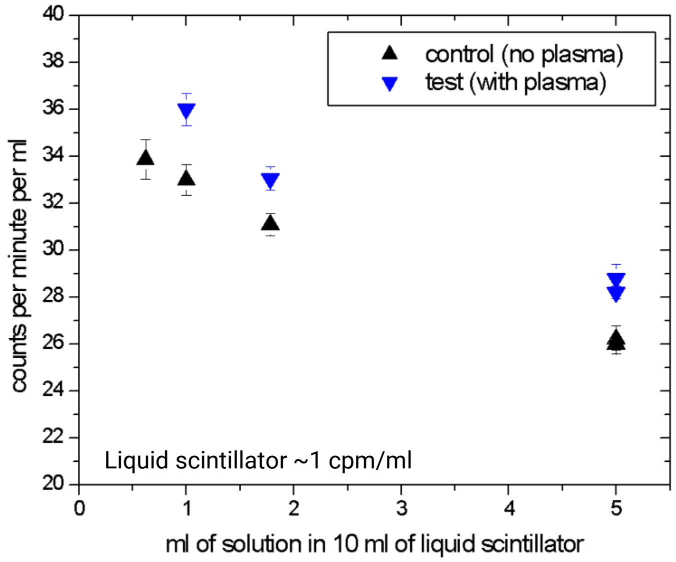
- No modeling tasks at this point

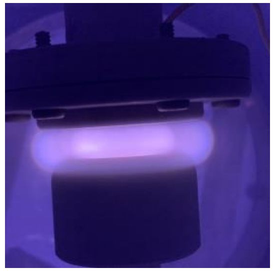
Initial Test Plan

- We have started assembly of the vacuum chamber, detector installation and calibrations and are ramping up electrochemical loading experiments with commercial palladium foils (0.05 to 0.25 mm thick)
- We plan on running el-chem experiments with a series of detectors first without ion or laser beams
- Procurement of the ion gun is in progress
- Preparation of etched palladium films for laser plasmon excitation experiments is in progress (next slides)
- We have had initial conversations with detector (Igor Jovanovic) and ex situ metrology teams (Rob Duncan)

Initial Results







- Deuterium partial pressure as a function of time during el-chem loading of Pd foils
- This shows that the integration of an el-chem cell on one side of a Pd foil and vacuum on the other side is working
- Funded pre-pandemic by Google, co. C. Berlinguette

- Preliminary data from ex situ scintillation counting of tritium decay in el-chem solution (D_2O, D_2SO_4) plus liquid scintillator following el-chem loading and exposure of Pd to pulsed ion beams at <1 keV
- Special thanks to R. Abergel for scintillation counter measurements
- Funded pre-pandemic by Google, co. C. Berlinguette

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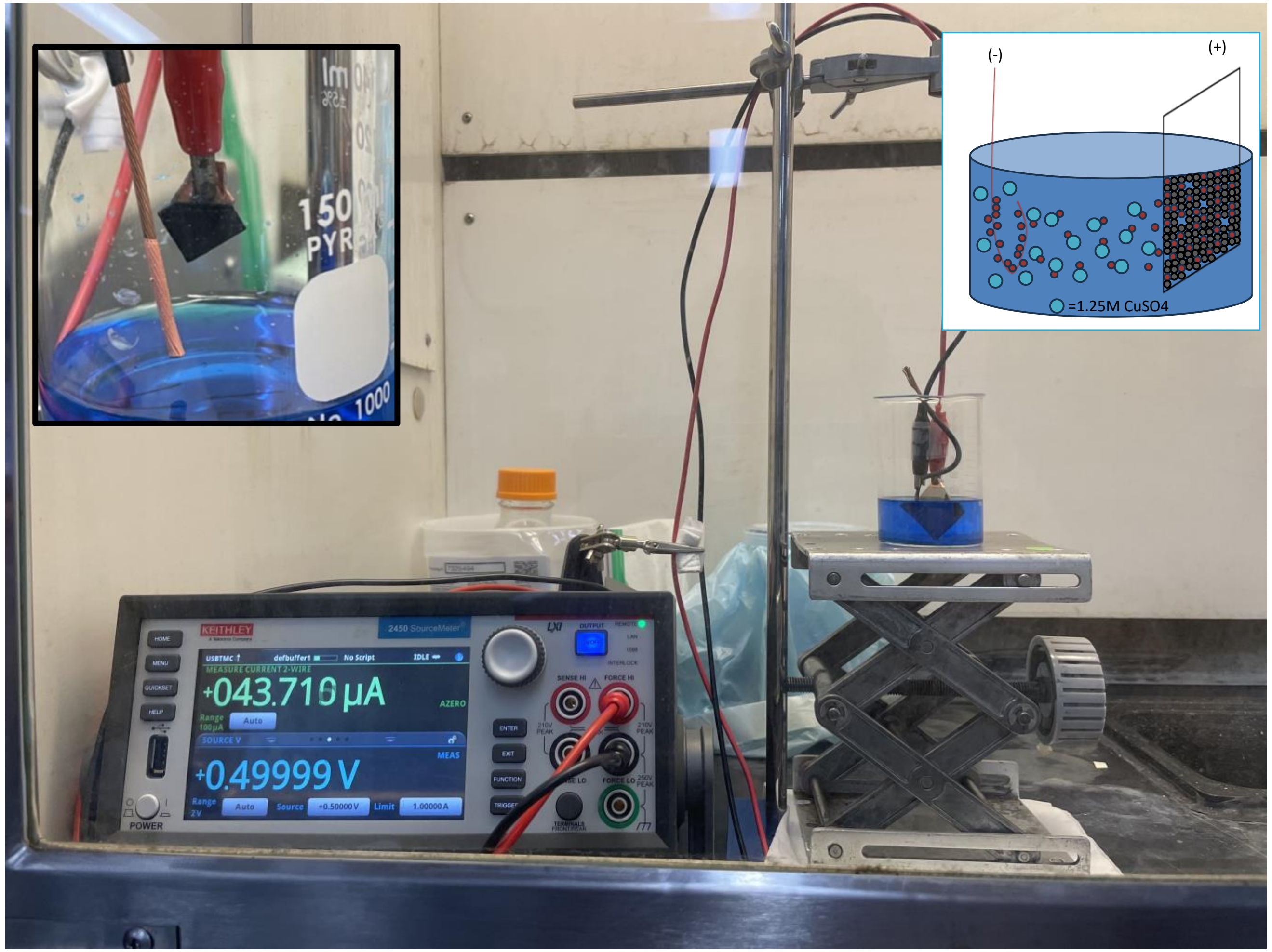
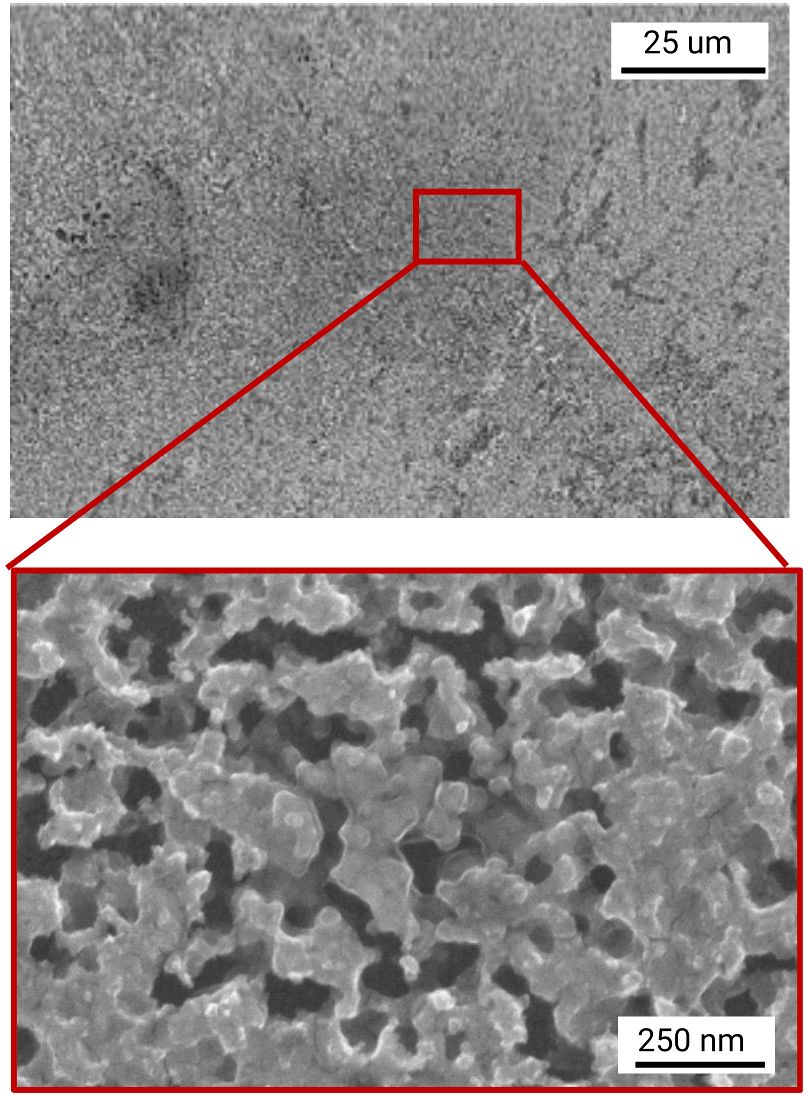
Initial Results (UC Davis, Jeremy Munday)

- Preliminary nanoporous Pd





Plans for Next Quarter (Oct – Dec, 2023)

- We plan on setting up electrochemical loading of Pd foils and then run el-chem experiments with a series of detectors
  - First runs are without ion or laser beams

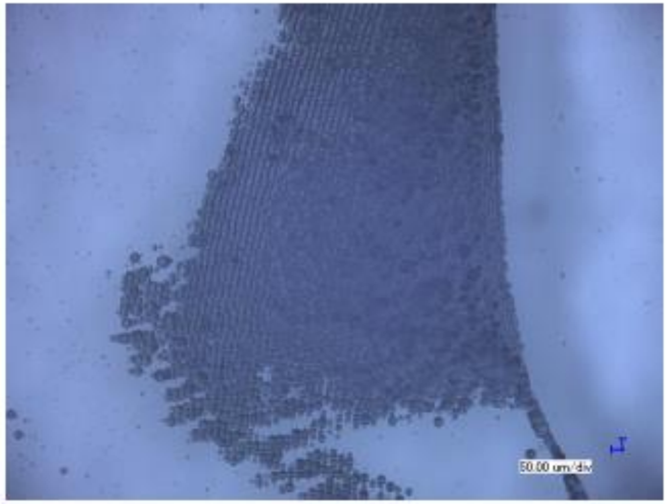
- Procure, and receive and install the ion gun (delivery date tbd)

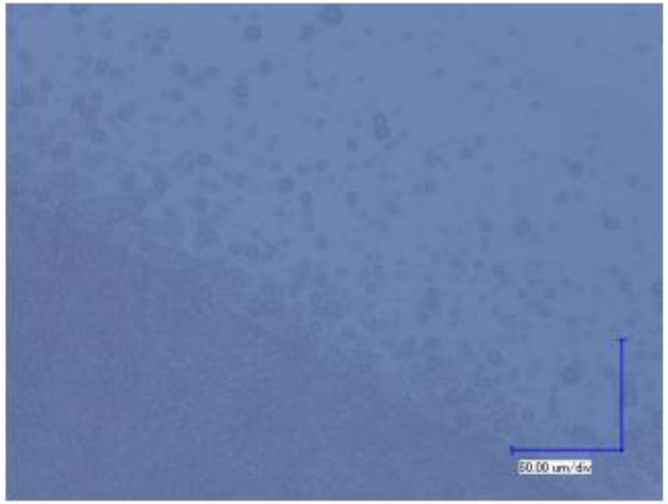
- Commence optical characterization of etched palladium films for laser plasmon excitation experiments

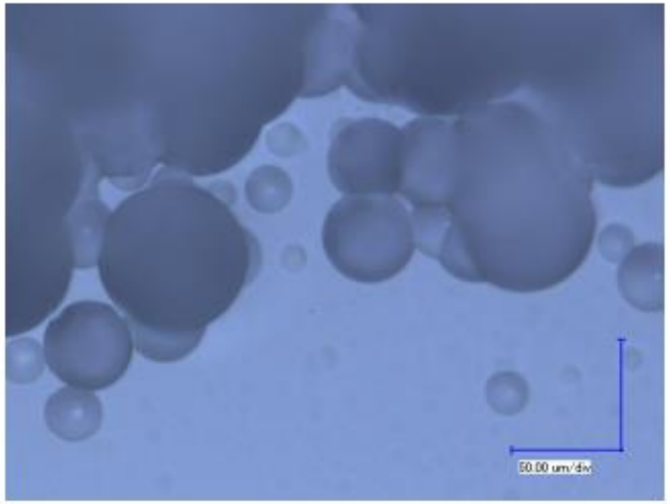
- Define action plans with detector (Igor Jovanovic) and ex situ metrology teams (Rob Duncan) and commence collaborations

Extra slides

CR-39 nuclear track detector plates can complement ion detectors for detection of low rates of ionizing radiation



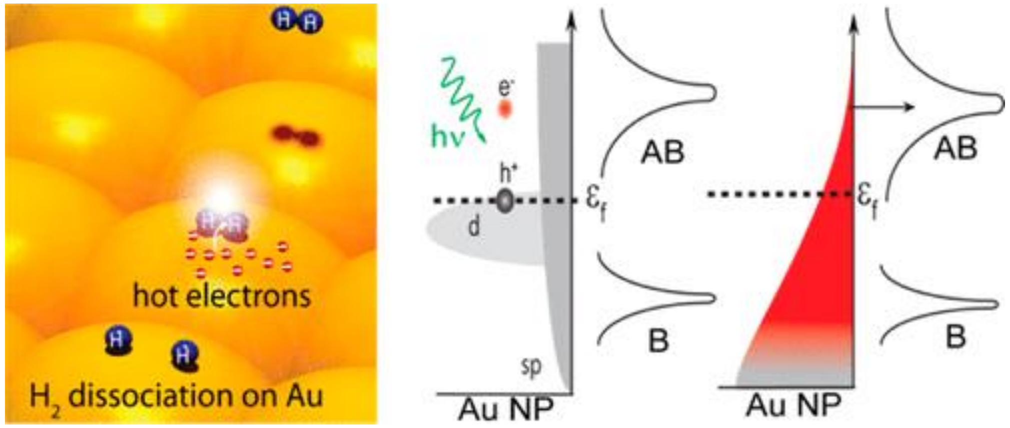




- PW laser-ion acceleration from few MeV/u protons to gold ions, 1 h, 70 C, KOH etching protocol
- CR-39 detector plates can be wrapped in Al foil to prevent damage, while retaining sensitivity to MeV protons and T ions
- dE of 3 MeV protons in 25 um Al ~0.6 MeV

Can we affect the electronic structure of transient d-d molecules with high electric fields from laser driven plasmons on deuterium loaded Pd nano-structures ?

- High electric fields from laser-driven plasmons at nanostructures can couple into the electronic structure of hydrogen molecules, leading to dissociation (dE~15 eV) (Mukerjee 2013)
- In a nuclear analog, we will quantify d-d fusion yields in the presence of electrical fields from plasmons that are modulate screening potentials and tunneling probabilities
- If successful, this will be a demonstration of eV-processes affecting MeV-nuclear processes and offer an elegant way to study tunneling physics and control screening processes



•Plasmon assisted dissociation of H_2 on gold nanoparticles using visible light.
•S. Mukherjee et. al, *Nano Lett.* 2013, 13, 1, 240–247, https://doi.org/10.1021/nl303940z

- Our project summary for public release:
- We propose to quantify nuclear reactions, such as the deuterium-deuterium fusion reaction at relatively low reaction energies, below 500 eV. At these low energies, known nuclear fusion processes lead to very low fusion reaction rates, so low that there is no reliable data in this regime today. There has been ample speculation and reports of high fusion rates at low energies, including claims of so-called “cold fusion”. In our project we will combine an electro-chemical cell with ion beams for deuterium loading and defect engineering of palladium. DD-fusion reactions will be excited by electro-chemcical loading directly, with less than 500 eV d+ ions and or laser driven plasmons. We will quantify reaction rates with nuclear diagnostics, including detectors for neutrons and MeV-scale ions. A mass spectrometer will quantify low energy ions from hypothetical reactions that couple directly to the Pd lattice. Ex situ scintillation counting and mass spectrometry will track tritium and transmutation products. We can quantify LENR in an underground lab with better shielding in year 2 to improve sensitivity and signal to noise ratios in our data. In our collaboration we integrate expertise in el-chem loading (Berlinguette, University of British Columbia), ion beams & nuclear detection (Schenkel, LBNL), laser-plasmon excitation (Munday, UC Davis) and PD alloy engineering (Tom Claytor). We aim to quantify low energy nuclear reactions for a series of well-defined experimental conditions. If successful, we will identify key parameters for scaling of nuclear reaction rates towards energy gain and future power production.