Precursors and the Fusion Reactions in Polarized Pd/D-D_2O System: Effect of an External Electric Field

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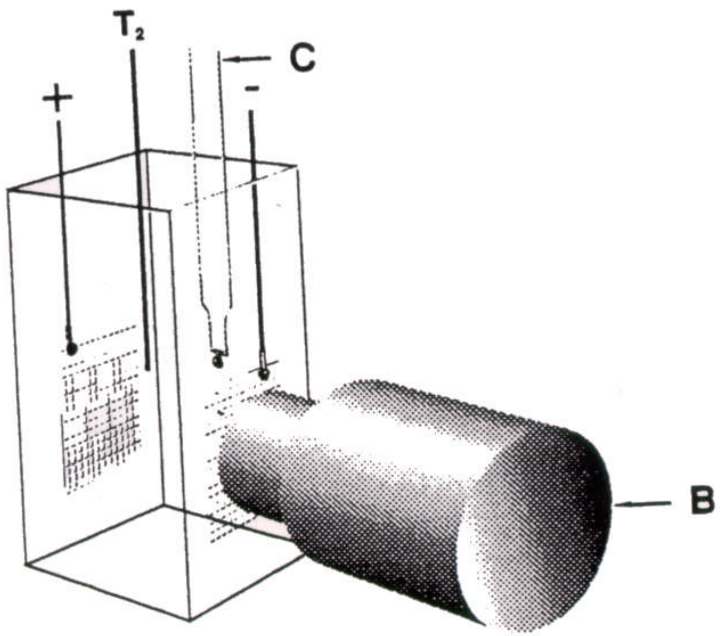
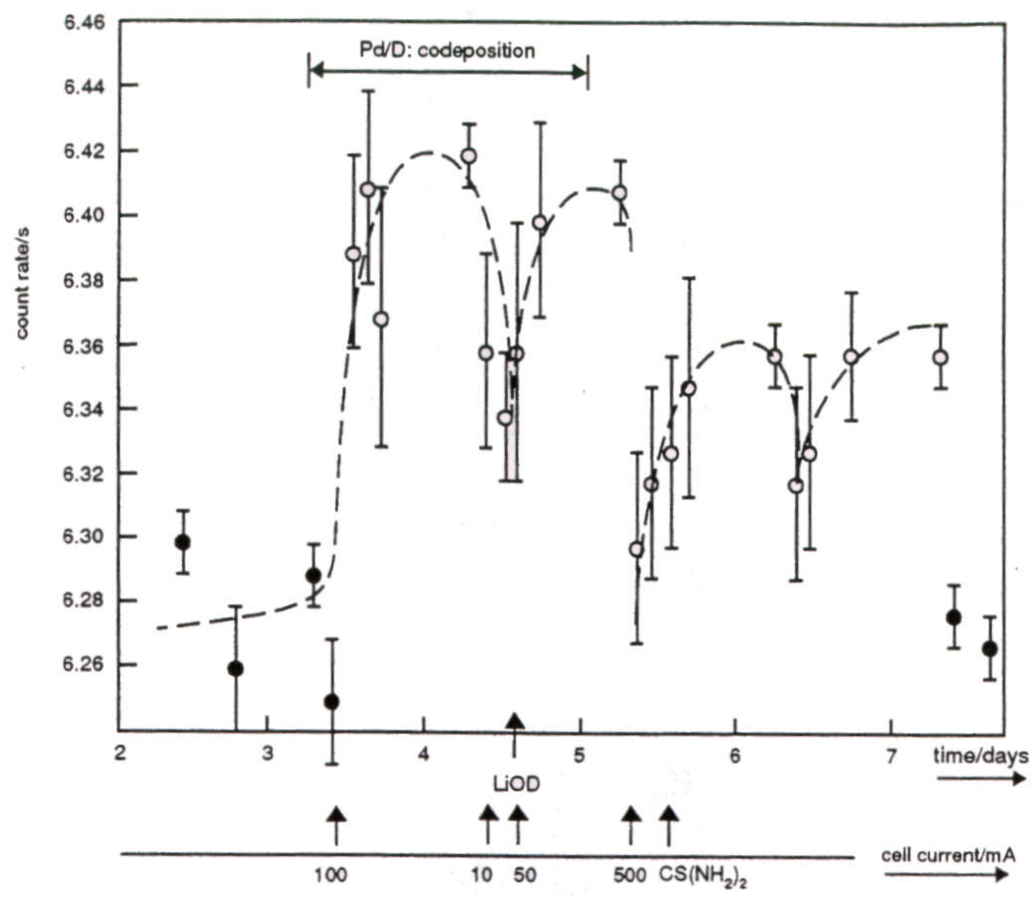
Advantages of Pd/D Co-Deposition

- **Deposits Pd in the presence of evolving D_2**
- **Short loading times—measurable effects within minutes**
- **Extremely high repeatability**
- **Maximizes experimental controls**
- **Experimental flexibility**
  - **Multiple electrode surfaces possible**
  - **Multiple electrode geometries possible**
  - **Multiple cell configurations possible**

Emission of Low Intensity Radiation

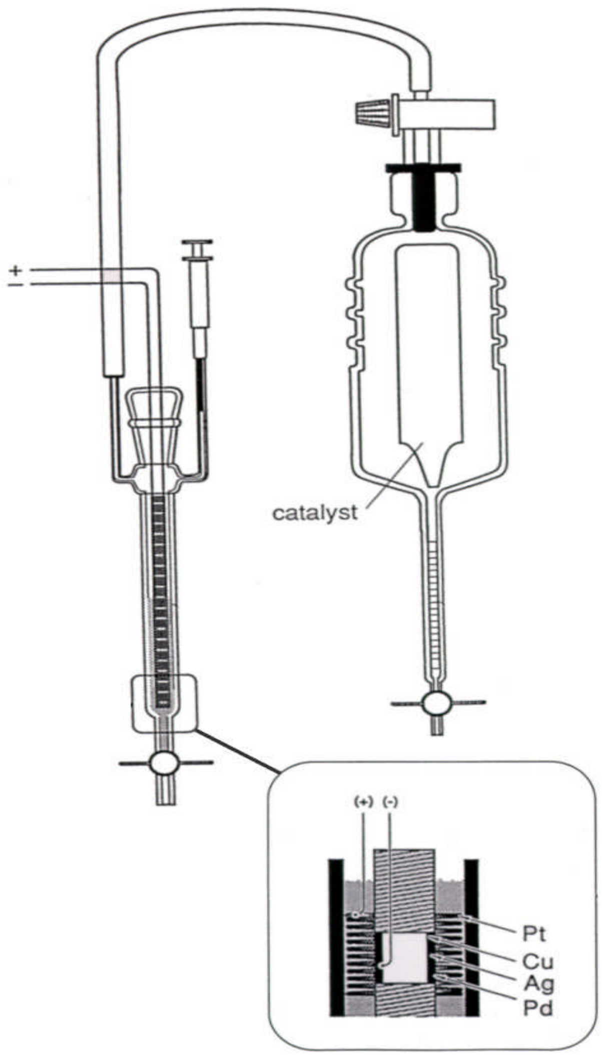
Physics Letters A, Vol. 210, pp. 382-390 (1996)

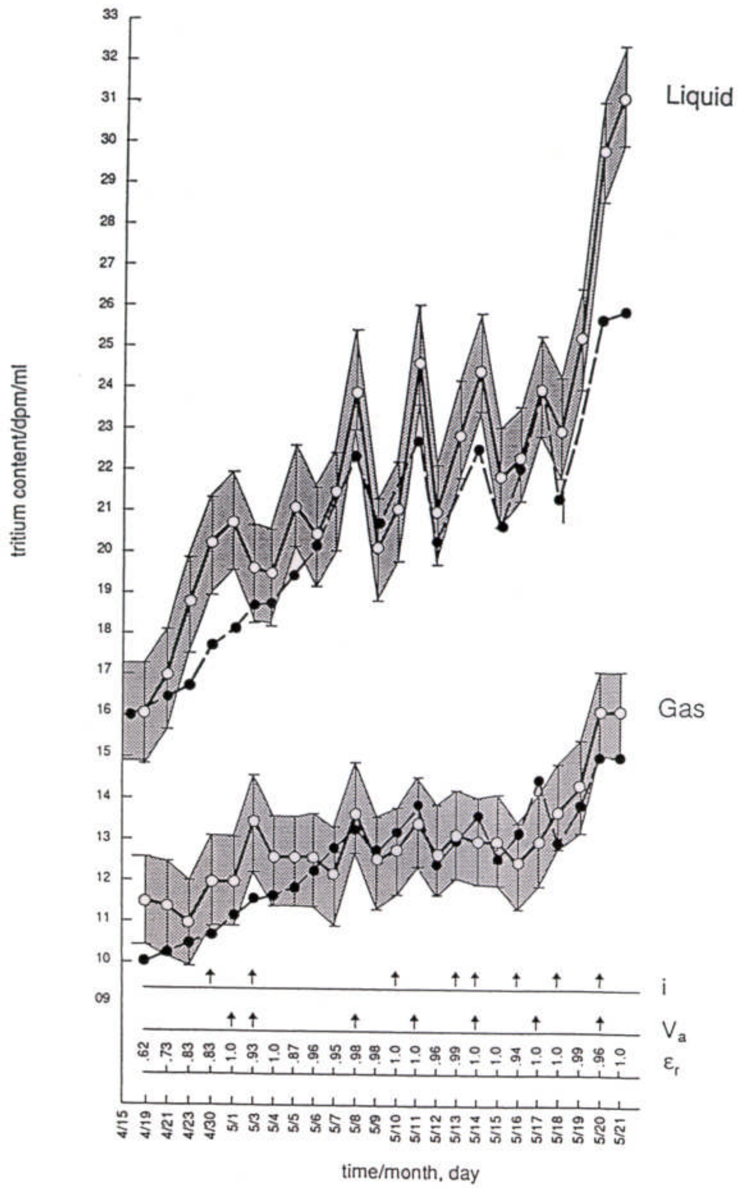




Tritium Production

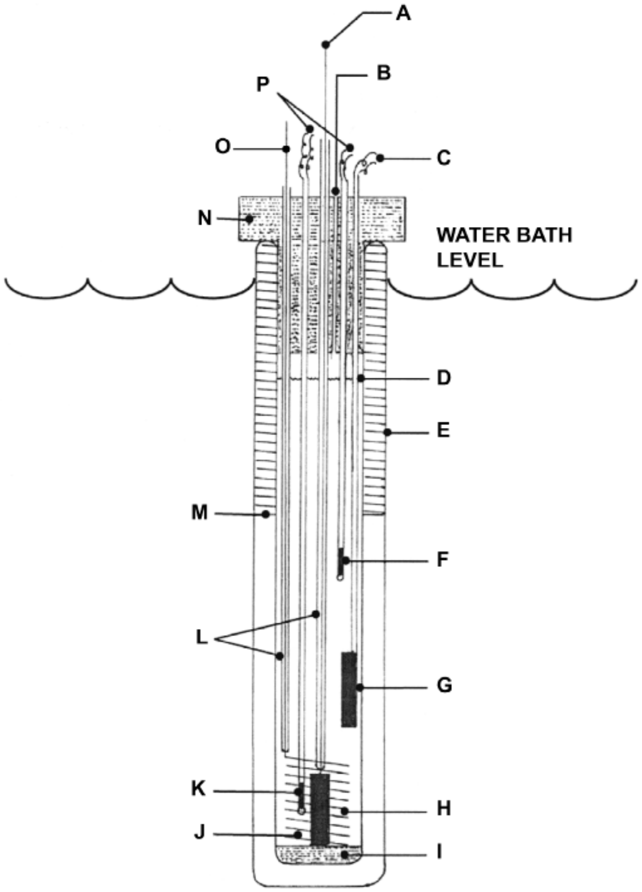
Fusion Technology, Vol. 33, pp.38-51 (1998)

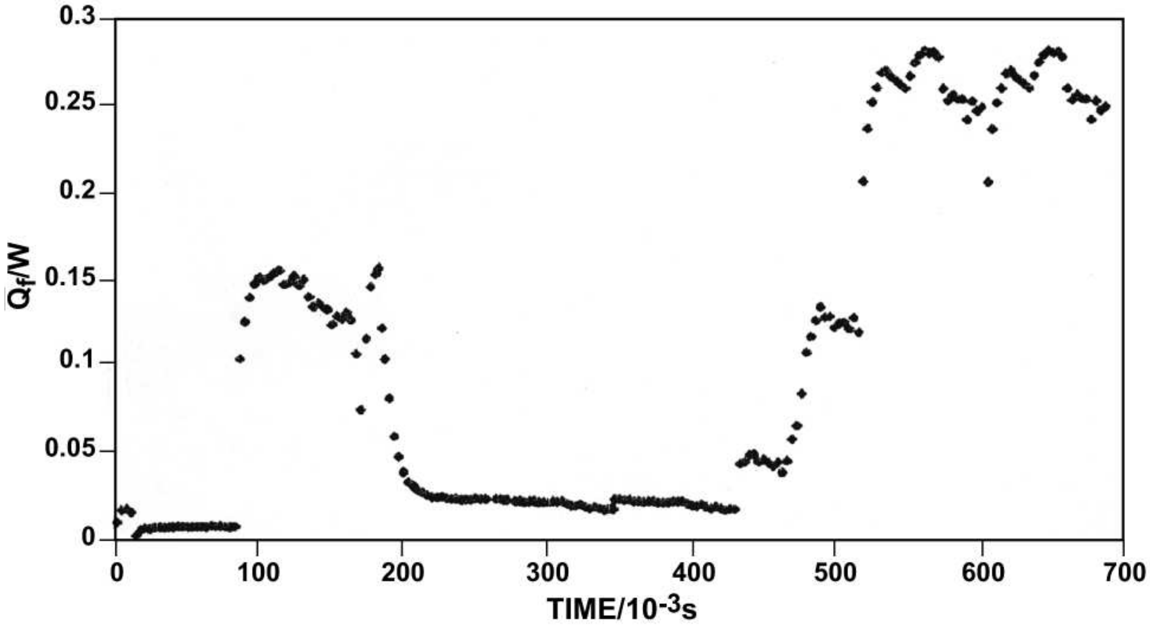




Excess Enthalpy Generation

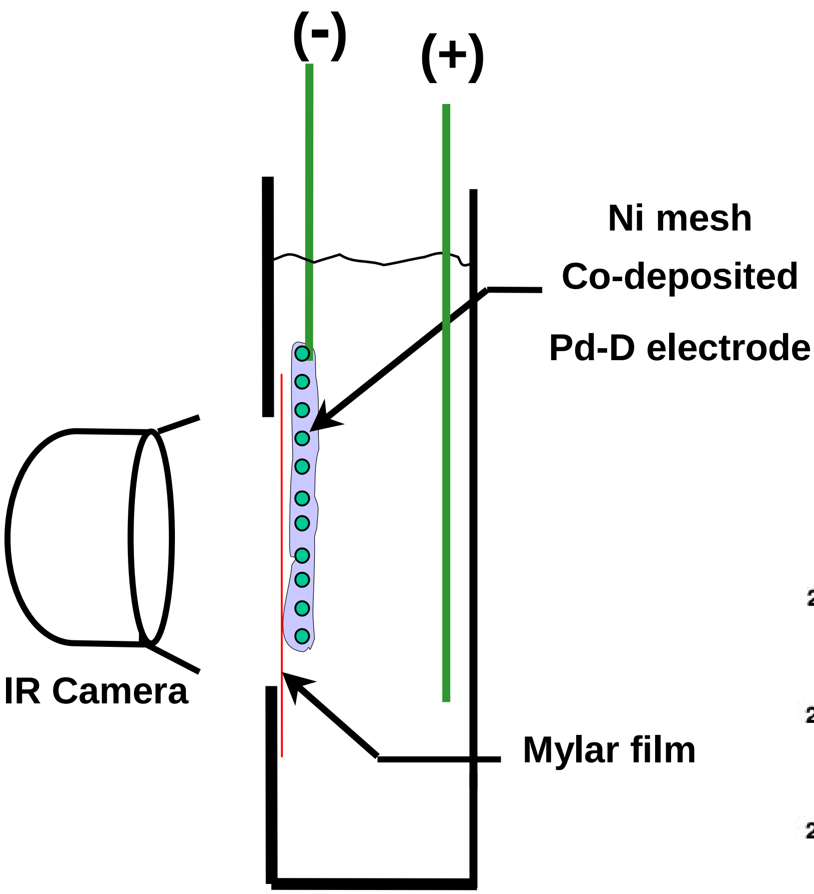
Thermochimica Acta, Vol. 410, pp. 101-107 (2004)

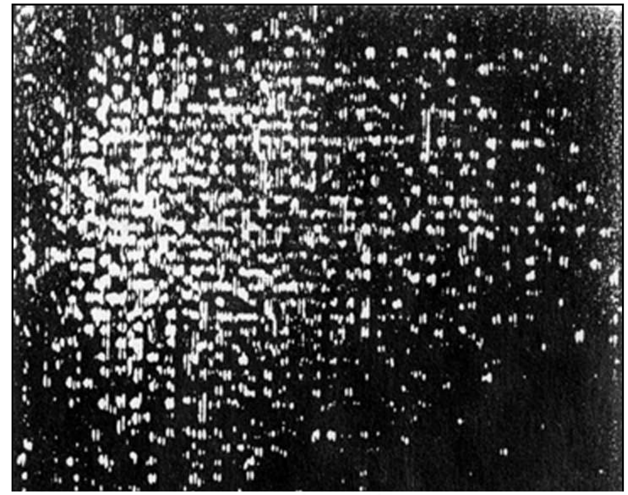


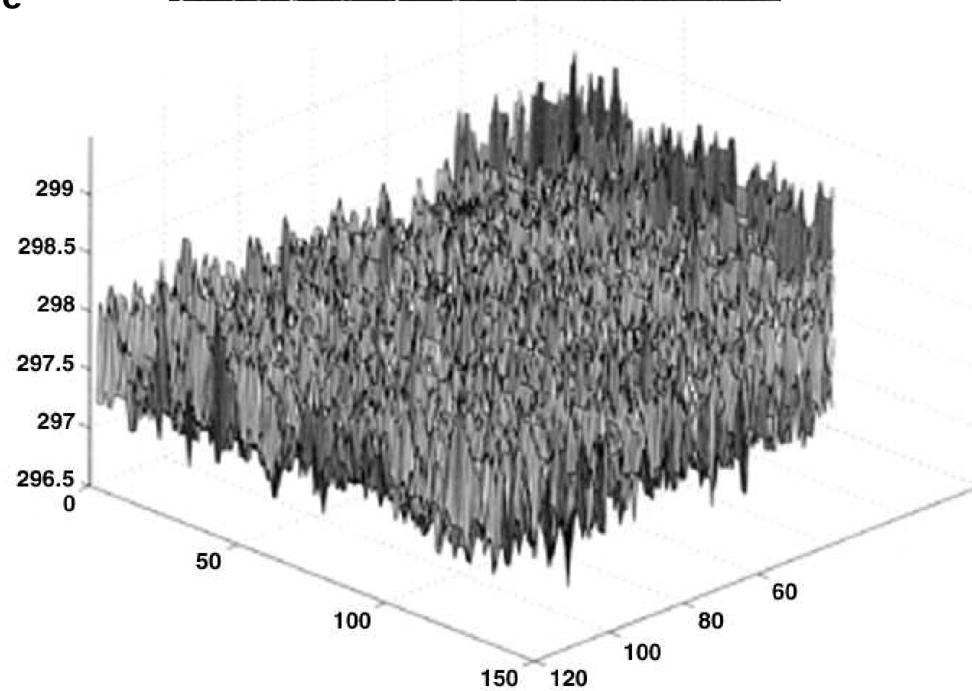


Formation of ‘Hot Spots’

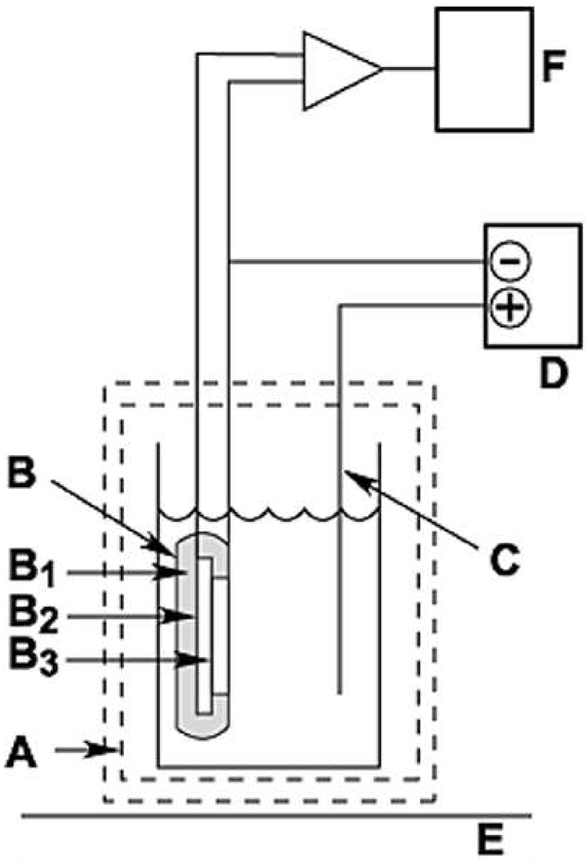
Il Nuovo Cimento, Vol 112A, pp. 577-585 (1999)

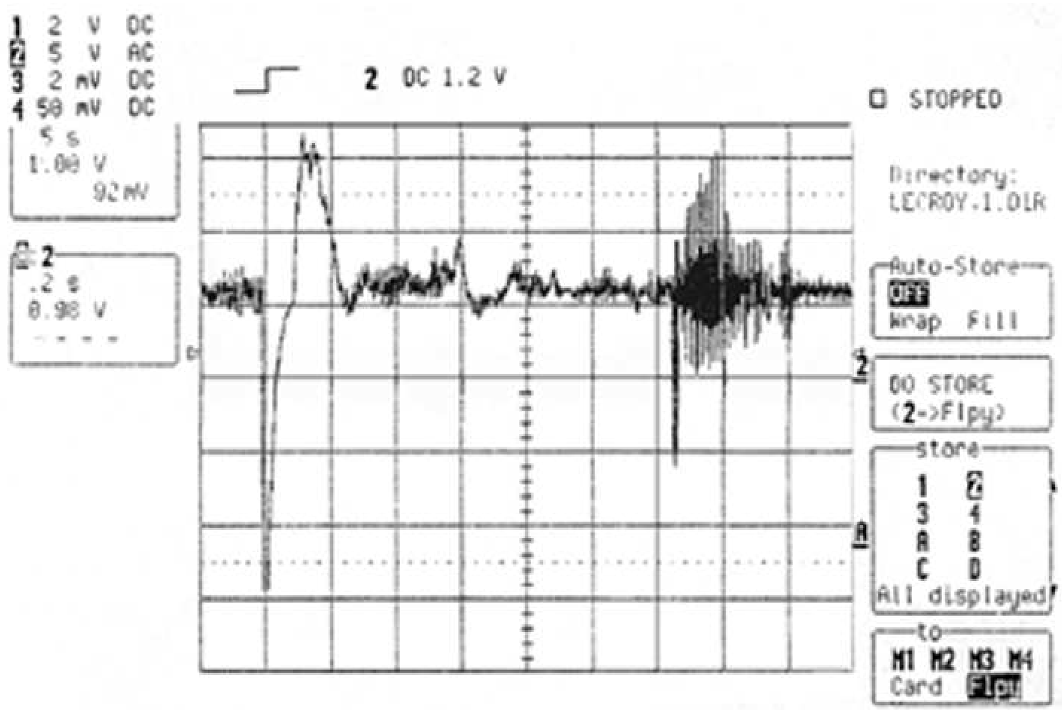






Piezoelectric Response to Pressure and Temperature vs Time





External Electric Field Experimental Configuration

Electrodeposit Pd onto Au electrode:
i_d = 1 mA cm^{-2} for 8 hrs,
3 mA cm^{-2} for 8 hrs,
5 mA cm^{-2} until Pd^{2+}
is completely reduced

↓

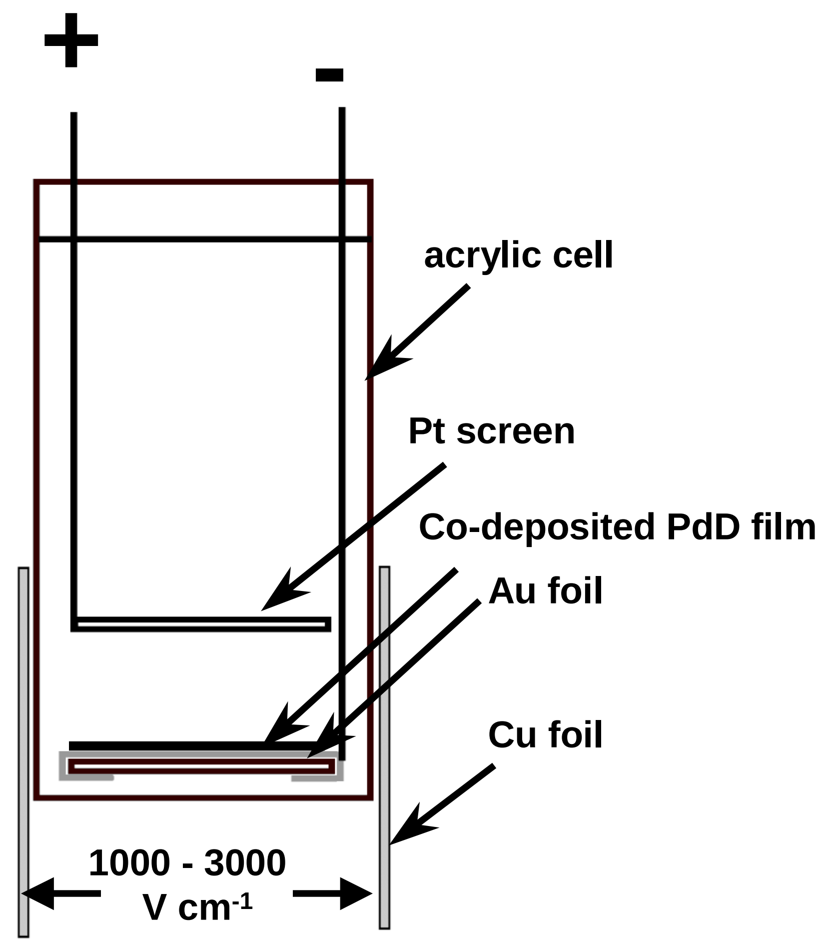
Increase cell current to maintain visible gas evolution
(~30-50 mA cm^{-2}) for 2-3 hrs.

↓

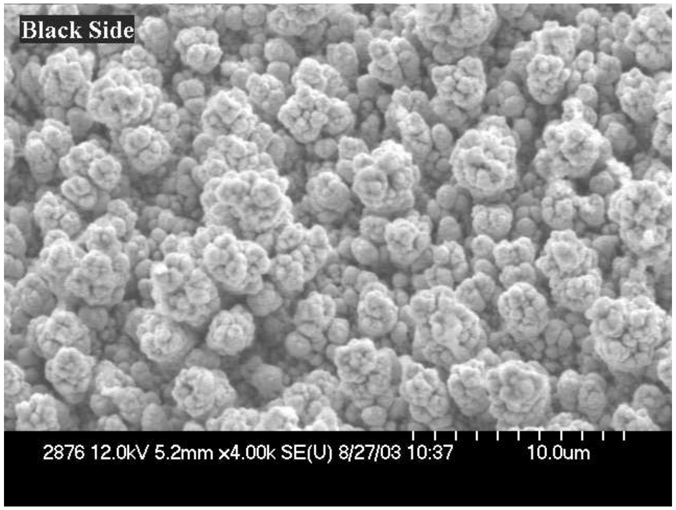
Apply external electric field.
Increase cell current
to ~100 mA cm^{-2}.

↓

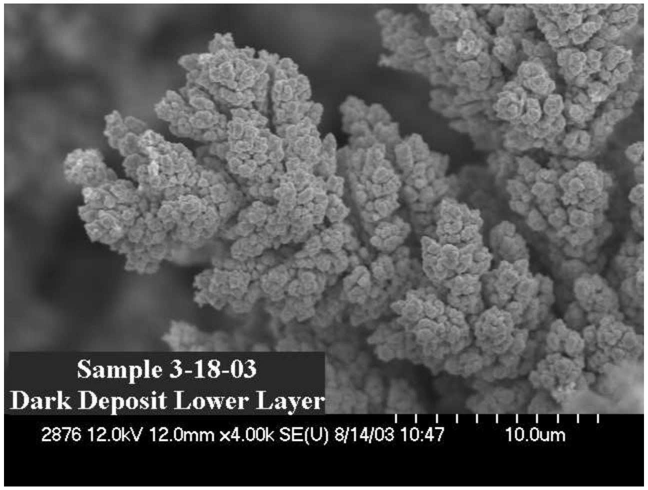
Terminate experiment after 48 hrs or more.



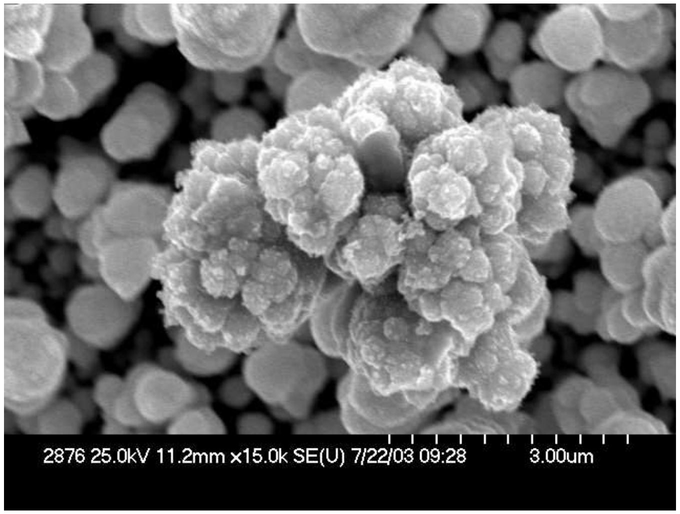
Morphology Changes – Minor Deformations



Pd/D structure in absence of electric field showing 'cauliflower-like' morphology of globules



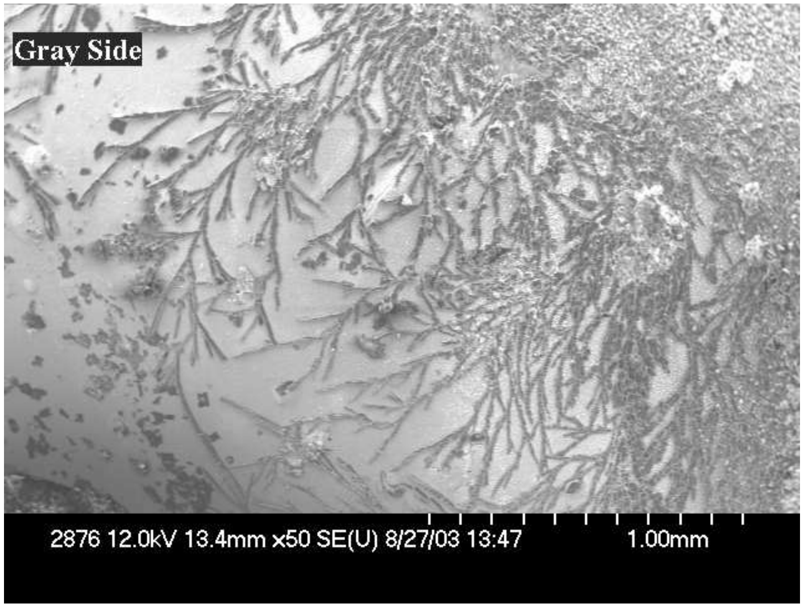
Reorientation of globules without change in size



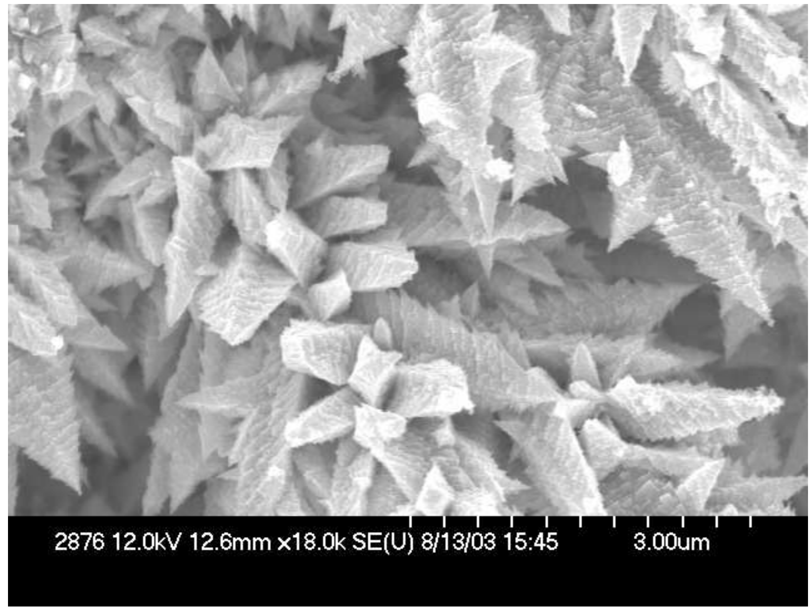
Separation of weakly connected globules

Morphology Changes – Minor Deformations

Formation of fractals (branches)



Production of dendritic growth



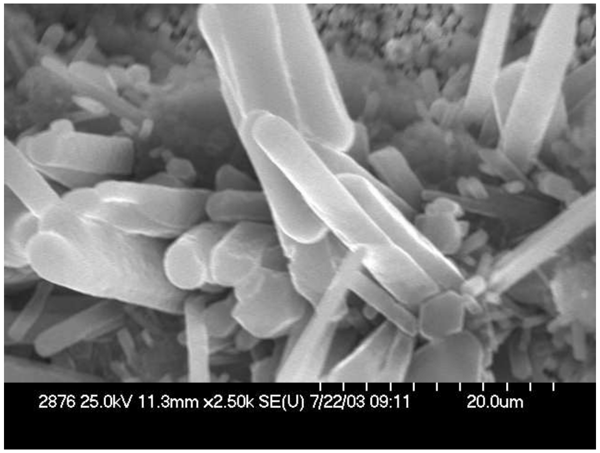
These features are the result of the combined action of:

(1) Current flow through a porous structure

(2) Evolving deuterium

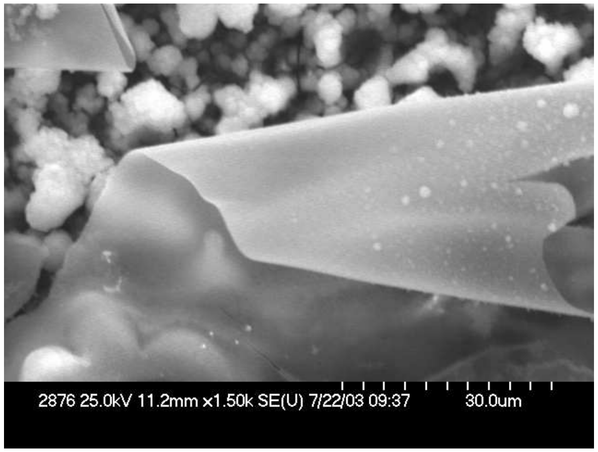
(3) The electric field on the separated micro-globules suspended in the electrolyte and restricted by the porous structure

Morphology Changes – Reshaping of the Spherical Globules

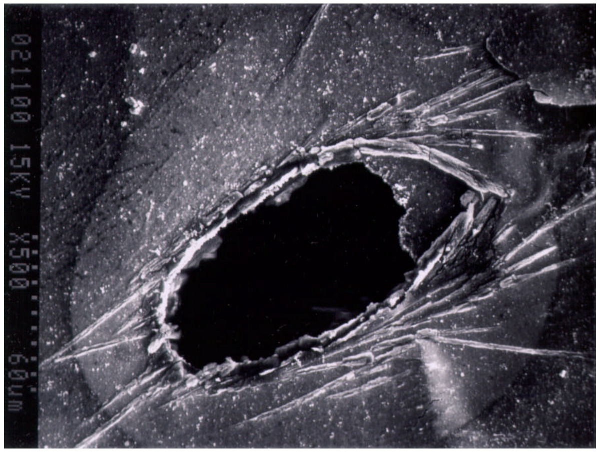


Rods (circular and square)

Long wires



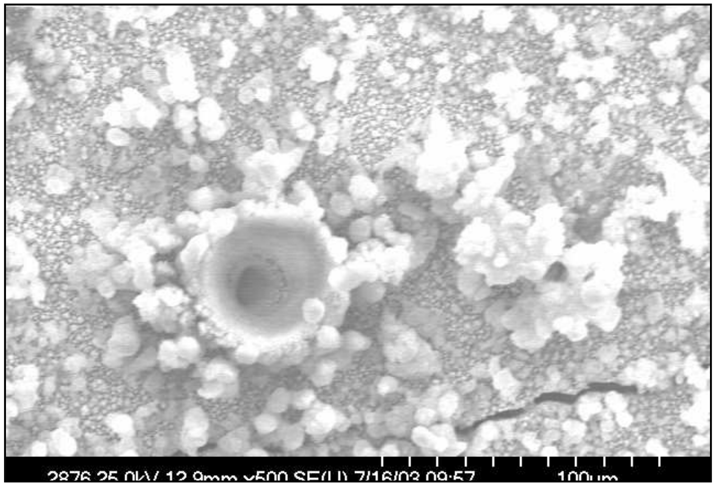
Folded thin film

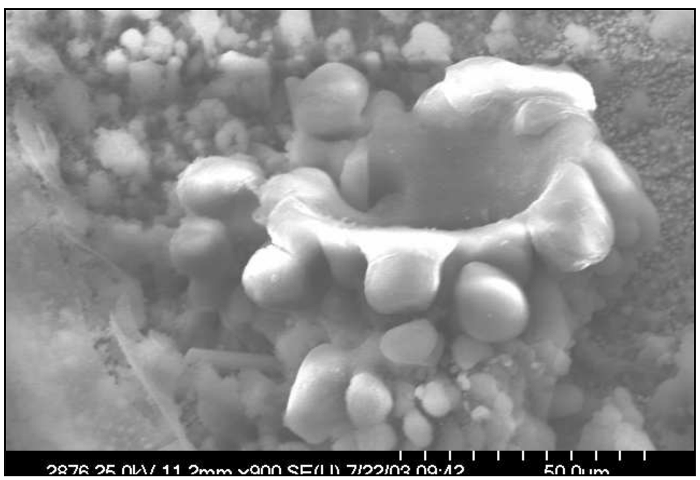


Crater

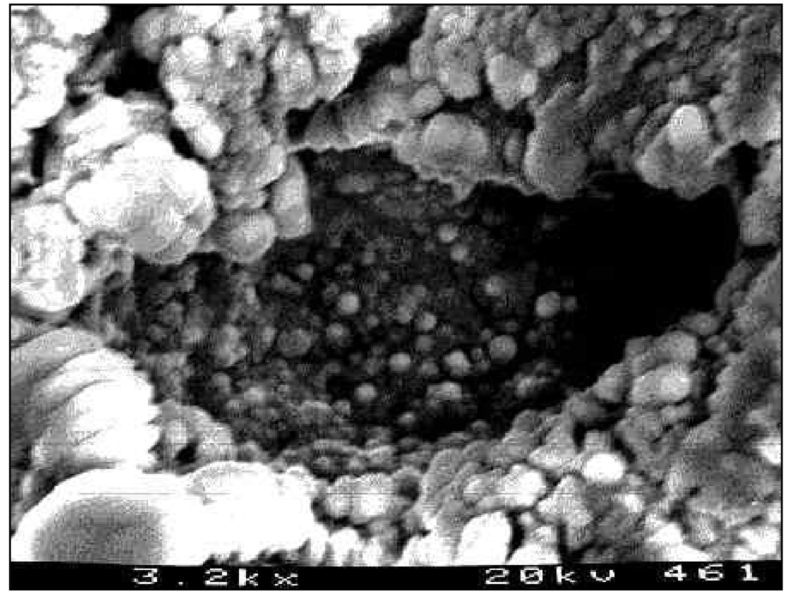
Morphology Changes – Reshaping of the Spherical Globules

Crater Formation (this work)



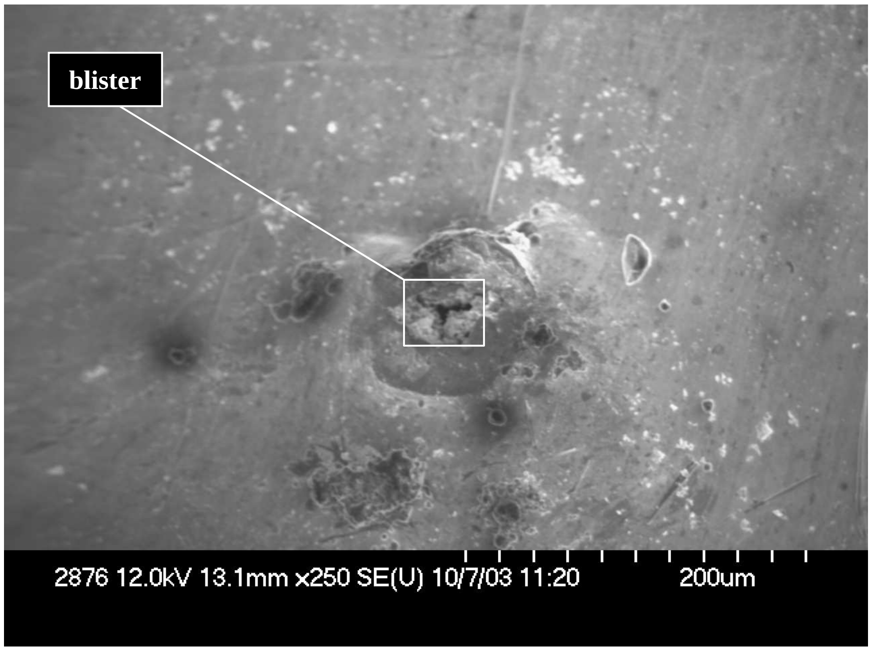


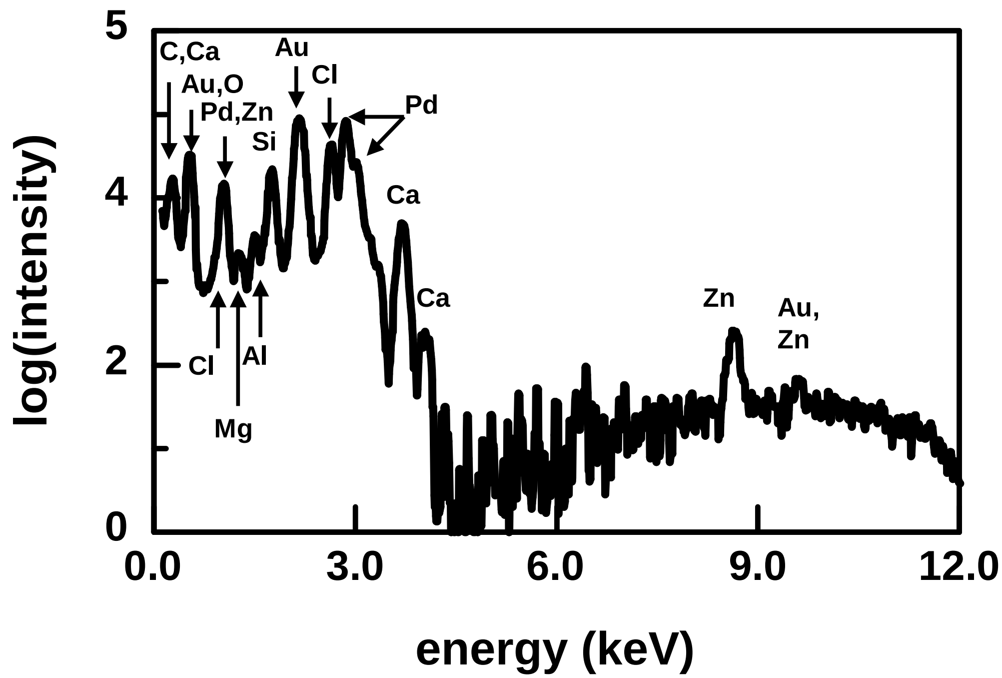
‘Sonofusion’ of Thin Pd Foils
Russ George 1996



- **Features suggestive of solidification of molten metal occurring under a liquid.**
- **Energy needed to melt metal is of a nuclear origin.**
  - **Should be reflected by chemical analysis of these features**

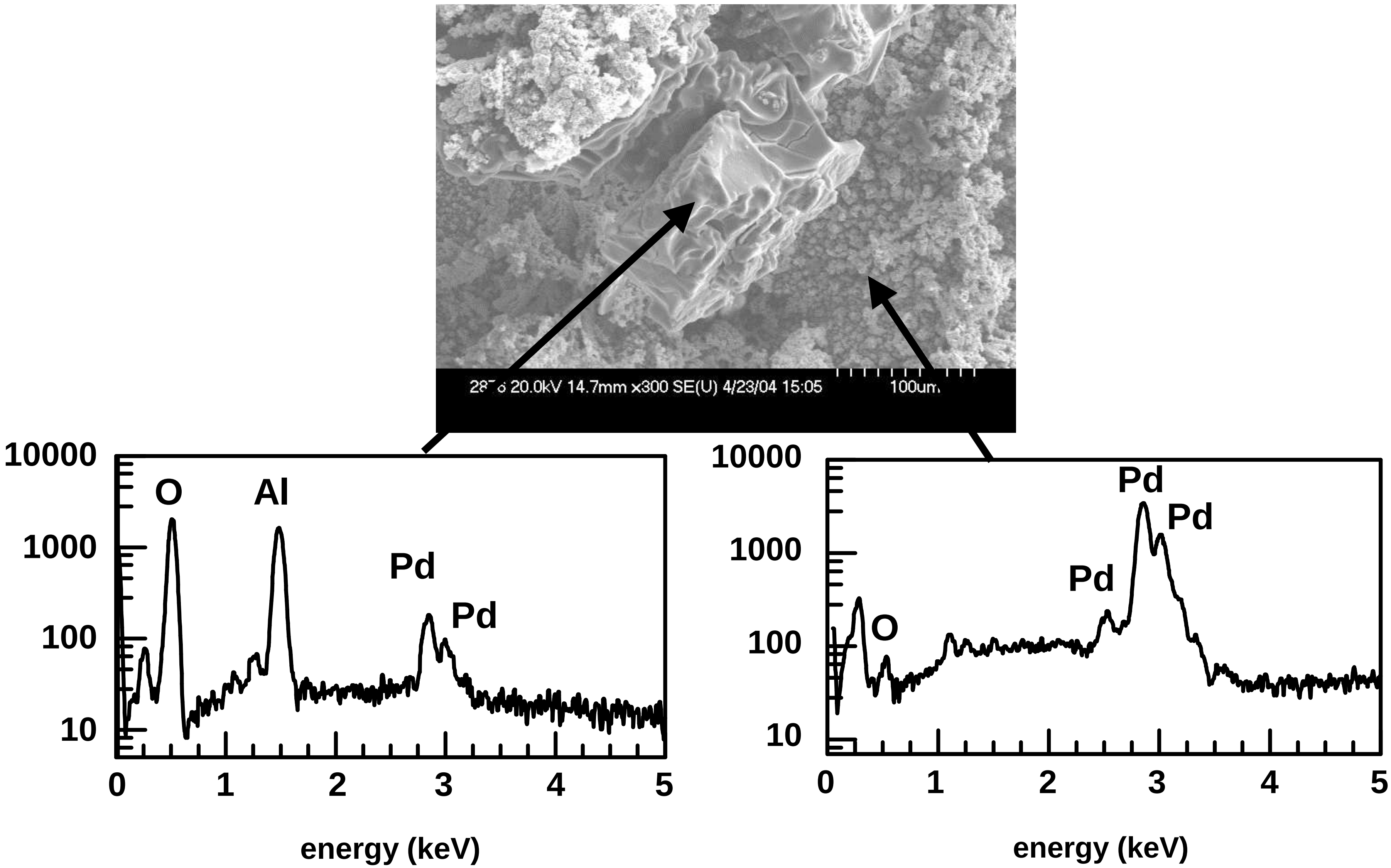
Chemical Composition of a Detached Thin Film (‘Blister’)



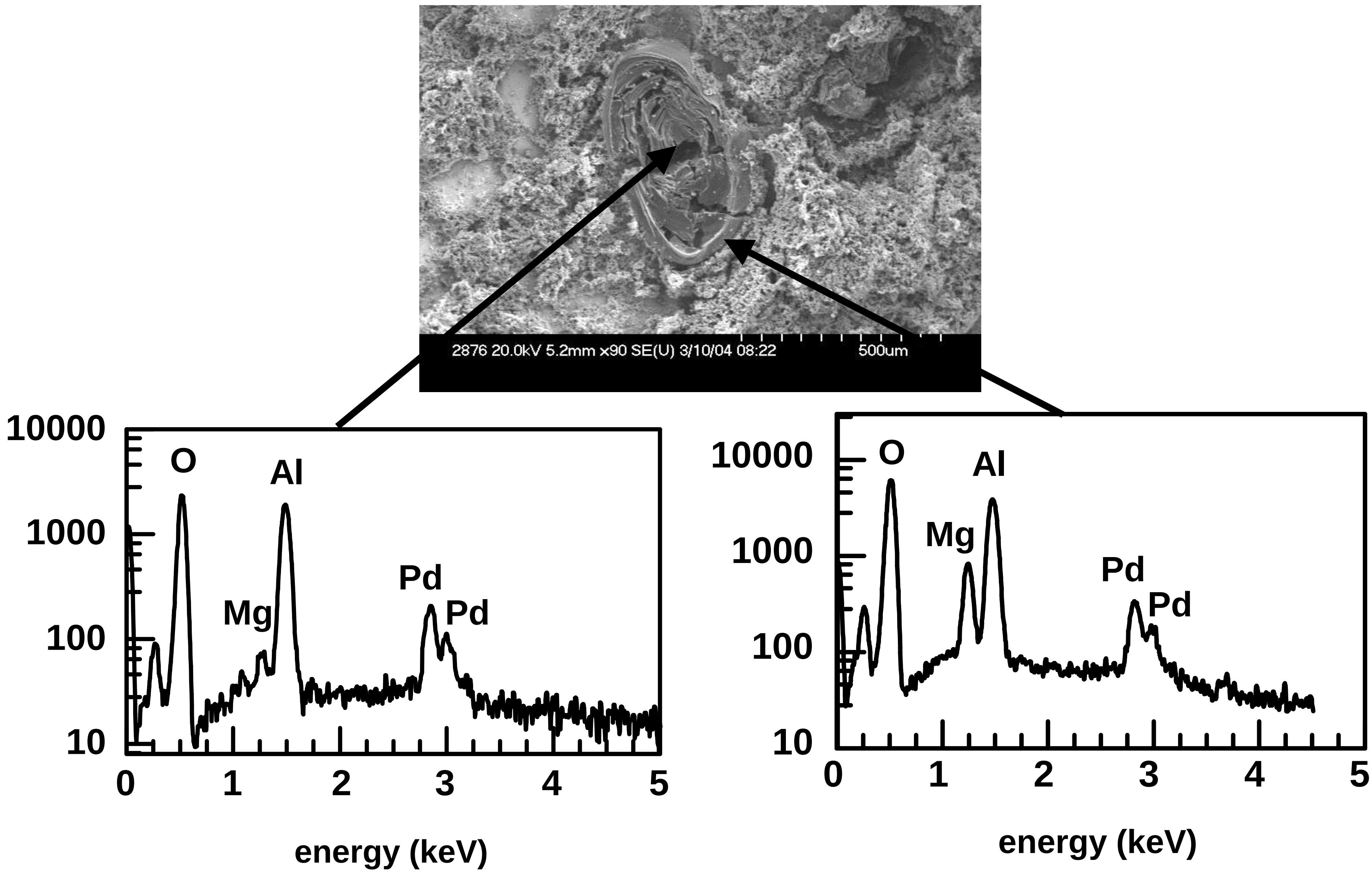


- Analysis of the ‘blister’ shows the presence of Ca, Al, Si, Mg, Zn, Au, O, and Cl.
  - Au, O, and Cl are present in cell components and cannot be attributed to nuclear events.
- Distribution of Ca, Al, SI, Mg, and Zn is not uniform suggesting that their presence is not the result of contamination.

Chemical Composition of a 'Boulder-like' Deformation and the Area Adjacent



Chemical Composition of the Inside and Outside Rims of a Crater



Characteristics of Systems Far from Equilbrium

- **The formation of new structures is always the result of an instability which may be due to either internal or external fluctuations to the system**
- **Fluctuation is always followed by the response which may bring the system to its original conditions or may produce a new structure**
- **The system's stability is determined by a complex interplay of kinetic and thermodynamic quantities (*ie*., no statement can be made that is independent of kinetic considerations)**
- **Chemical instabilities lead to spontaneous "self-organization" if the system is able to exchange part of the energy or matter with the outside world in order to establish a microscopic internal order (an open system must be maintained, if self-organization is to occur)**
- **As the overpotential is increased, the probability of cluster formation increases (increase in the rate of formation of hot spots)**
- **An external electric field assists the self-organization via events occurring at the interface (specifically the contact surface)**

Proposed Mechanism for the Formation of T, ^{4}He, and other Elements

- **Cyclic voltammetry of Pd/D-D_2O Indicates the presence of D_2^+ species in the Pd lattice: $D^+ + D^+ + e^- \rightarrow [(D^+\cdot e^-)\text{-}D^+]$**
  - **Formation of D_2^+ involves injection of an s-electron into an orbit. The s-electron effectively shields one of the D^+ ions.**
  - **D_2^+ undergoes s-electron capture (K capture) to form T and ^{4}He:**

    $[(D^+\cdot e^-)\text{-}D^+] + e_s^- \rightarrow [(D^+\cdot e^-)\cdots\cdot D^*]$, or $_1(X)^4$ a highly excited nucleus

    Beta emission yields He: $_1(X)^4 - e^- \rightarrow {}_2(He)^4$

    Proton emission followed by beta emission yields T:

    $_1(X)^4 - p^+ \rightarrow {}_0(X)^3 - e^- \rightarrow {}_1(X)^3 \rightarrow T$
- **An external electric field causes the Pd lattice to expand further allowing the formation of larger $[(D^+\cdot e^-)_n\text{-}D^+]$ molecule-ion aggregates:**

  $[(D^+\cdot e^-)_n\text{-}D^+] + D^+ + e^- \rightarrow [(D^+\cdot e^-)_{n+1}\text{-}D^+]$ and

  $[(D^+\cdot e^-)_n\text{-}D^+] + [(D^+\cdot e^-)_m\text{-}D^+] + e^- \rightarrow [(D^+\cdot e^-)_{n+m}\text{-}D^+]$
  - **These molecule-ions interact with the energetic s-electrons to yield precursor $Pd\cdots\cdot[(D^+\cdot e^-)_n\text{-}D]$. The precursor is the last step in the set of processes comprising the charging of the Pd lattice. The nuclear event is of the type: *precursor + trigger → unstable nucleus → stable element***

Conclusions

- **An external electric field changes the shape of the individual globules of the "cauliflower" structure of the Pd/D co-deposited material. With the shape change there is a change in the defects density as well as in the stress field intensity. Both these factors affect the interaction between the D^+-complexes and the Pd lattice, and contribute to the formation of the $Pd \cdots [(D^+ \cdot e^-)_n - D^+]_N$ domains.**
- **The concentration of the D^+-complexes is determined by the overpotential. The effect of an external electric field is minimal.**
- **Excess enthalpy is generated by highly energetic fast reactions that resemble "mini-explosions".This view is supported by IR imaging (hot spots), by the response of the pressure/temperature sensitive substrates (piezoelectric material) onto which the Pd/D films are co-deposited and by SEM examination and analysis of selected isolated spots showing elements not originally present.**
- **The triggering activities (to initiate fusion reactions) are located within the first few atomic layers and, most likely, involve changes in the electronic structure of this region. These changes are transferred deeper into the Pd lattice where the nuclear events occur.**
- **The nuclear events, to form T, ^{4}He, Si, Ca, Mg, Zn, Al, etc., are of the type: *precursor + trigger → unstable nucleus → stable element***

Acknowledgements

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  - Mike Melich for financial support
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