Condensed Matter "Cluster" Reactions in LENRs

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Abstract

In this paper we first point out evidence for condensed matter cluster formation based on thin-film electrolysis. Next, measurements of superconductivity in condensed matter deuterium "clusters" in dislocation sites loaded-deloaded palladium thin films are briefly reviewed, followed by a discussion of techniques under study to increase the number of such sites per unit volume of the electrodes. Estimates for resulting "cluster reaction" rates – flow enhanced Pycnonuclear fusion are given. If successful, this approach offers a "Roadmap" for future power unit based on thin films and clusters.

Introduction

There is mounting evidence for localized reaction sites in many cold fusion and low energy nuclear reaction (LENR) experiments. Hot spots and damage spots on electrodes have been widely reported (e.g, by Srinivasan, Mizuno, Dash, Boss, …). Also, there have been detection patterns noted in our various types of experiments (Bead x-ray film, transmutation product pattern, MeV charged particles tracking pattern in CR-39 detectors, and observation of soft X-ray beamlets in pulsed plasma bombardment experiments). These observations indicate that localized reaction sites frequently occur and can dominate the reaction mechanism. More insight into the possible character of these sites comes from our earlier studies of the formation of superconducting "clusters" of hydrogen isotopes in dislocation loops formed in thin film palladium electrodes. That work is reviewed next, followed by a discussion of implications for creating highly reactive electrodes based on a high density of these condensed matter "clusters" in the host electrode material.

Condensed Matter Cluster Characteristics and Electrode Fabrication

The squid magnetic measurements described in Ref. 1 show "clusters" have characteristics of a type- II superconductor (See Figure 1). Cluster regions can have hydrogen densities approaching 10^{24}/cc (See Figure 2). Dislocation loop cluster type electrodes are fabricated by cyclic loading-deloading, hence being named "Dislocation Loops by Repetitive Loading-Deloading (DLRLD)"electrodes. These DLRLD electrodes are based on studies where high loadings in dislocation loops in treated Pd have exhibited properties associated with a superconducting phase termed a "cluster." However, the low fractional volume of the clusters (which is where the fusion producing reaction would occur) limits total reactions to low levels. Thus, a second type of cluster forming electrode that employs a manufactured nano-porous structure is under study.
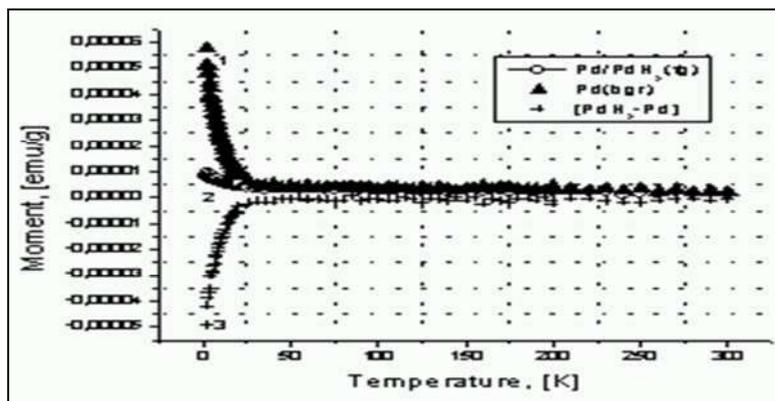
Figure 1. The magnetic moment of H_2- cycled PdHx(fg) samples in the temperature range of $2 \leq T < 50$ K is significantly lower than M(T) for the original Pd(bgr) single crystals.
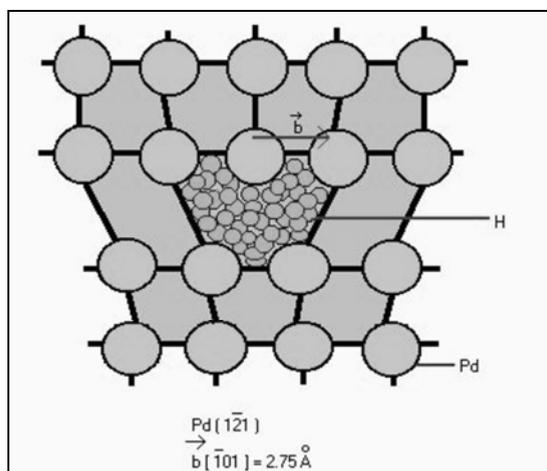

Figure 2. Squid magnetic measurements show clusters have characteristics of a type- II superconductor. Cluster regions can have hydrogen densities approaching 10^{24} 10^{24}/cc.

Fabrication

Cold worked Pd foil is used for Pd/PdO production. Prior to oxidation, the Pd substrate is annealed in a vacuum. It was then briefly treated in an oxygen-butane torch to produce a stable oxide layer, about 40-nm thick. Samples were electrochemically cycled to create a hydrogen filled dislocation structure in the Pd/PdO. The samples serve as the cathode, and a Pt anode is employed along with a high purity electrolyte. Electrochemical "cycling" involves periodically switching the cathode-anodic polarizations (loading – deloading) of the sample. After achieving a cathode loading up to x = H/Pd = 0.7, the voltage polarity is switched to the anodic regime to extract hydrogen from the volume of the lattice. To remove all weakly bound residual hydrogen atoms, the loading–deloading cycles are repeated 5-10 times. The samples are then annealed in a vacuum at 300°C for several hours.

Loading Measurements

A high-vacuum thermal desorption technique is used to estimate residual hydrogen concentration in the PdHx and Pd/PdO:Hx samples (Fig. 3). The samples were heated in a high vacuum (10^{-8} Torr) chamber with a quadruple mass-spectrometer. The hydrogen desorption peak area and the temperature of its maximum were found by analyzing the desorption species and comparing their yields to background data from the Pd(bgr) or Pd/PdO)bgr).
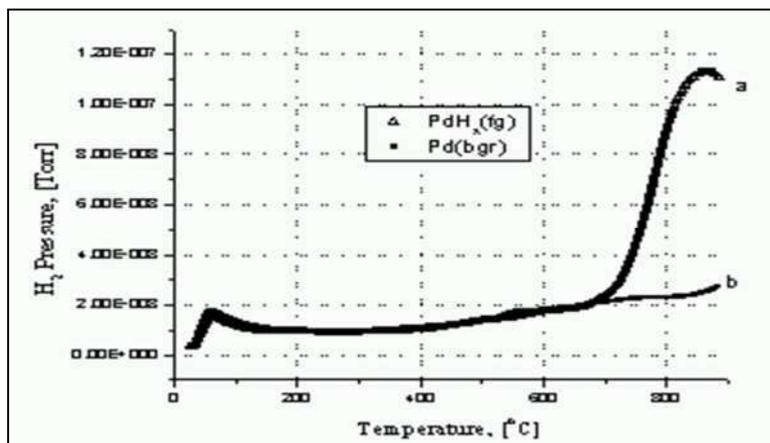

Figure 3. Thermal desorption analysis (TDA) performed with annealed Pd(bgr) samples in the temperature range of 20-900°C

Analysis of Cluster Loading

To obtain an average loading ratio x = H/Pd, special calibration measurements are done with a known mass (0.3 mg) of TiH_2 powder (decomposition temperature ~ 400°C.) A Comparison of the hydrogen pressure from this powder, with that of the PdHx samples gives the residual hydrogen content in the cycled Pd. The typical effective loading ratio is found to be x ~ $(4.5 \pm 0.5) \times 10^{-4}$, much lower than for any known stable phase of Pd hydride. Since this sample underwent annealing at a temperature of 570 K (decomposing the residual α-phase in the lattice), all remaining hydrogen detected is attributed to loading in dislocations, not in the regular lattice.

Cluster Parameters

Extrapolation of results of SANS measurements gives a radius R_H and binding energy of the residual hydrogen distribution with respect to dislocation cores. The Garlic-Gibson kinetics model is used for the kinetics of the second-order thermal activation processes observed in the thermal desorption analysis (TDA) measurements. Then, the activation energy of desorption (effective binding energy of hydrogen atoms within the lattice) is found to be ~ 1.6 ± 0.2 eV, well above the H-trapping activation energy of ~ 0.7 eV normally attributed to bulk hydrogen. This indicates that the hydrogen is solely bound inside the deepest core sites (at a radius R_H = 2.75 A, close to the Burgers vector or minimal radius of H capture in Pd). This suggests that all residual hydrogen is localized inside the dislocation loops (in the direction of Pd [121])

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determined by Burgers vector b [101] = 2.75 A. Then, the dislocation density N_d, the effective loading ratio inside the loops is determined by the simple formula: $x_{eff} = \sqrt{2}<x>/N_d<x>/b^2$., giving $N_d \sim (1.0-2.0) \times 10^{11}$ cm^{-2} and $<x> \sim (4-6) \times 10^{-4}$ Thus x^{eff} would be in the range of $1.0<x_{eff}<3.0$, suggesting superstoichiometric hydride formation in the deep dislocation cores.

Summary – clusters lead to localized SC

These results show that an anomalous diamagnetic response in these electrodes occurs below 30 K which is attributed to superconductivity in Pd hydride phase ("clusters") inside the deep dislocation cores. This interpretation is also consistent with the temperature and field dependencies of corresponding magnetization curves. Both their shape and field behavior have the characteristics of a non-linear, irreversible magnetization function of a type- II superconductor.

New Nano-Structure Film (NSF) Electrodes/Targets

Recently, a new type of electrode, the NSF electrode, was developed to create cluster formation in nano-porous structures manufactured on a Pd or Ni thin film electrode. The concept is to mimic the dislocation loops, but achieve a larger volumetric concentration or "packing fraction" than in the DLRLD electrode. This method used follows one originally developed by R.N. Rhonda of the International Nickel Plating Company. Palladium is deposited on a nickel substrate using an electroless deposition technique. An ammonium hydroxide solution dissolves palladium chloride tetrammine amine. Disodium EDTA keeps the palladium metal in the solution and the nickel substrate is etched and placed in the plating solution. Aqueous hydrazine is then added, destabilizing the palladium. Hydrazine is introduced using an infusion pump and the solution is placed inside an ultrasonic mixer. The destabilized palladium then plates the nickel substrate.

Auger spectroscopy performed on the electrodes confirms that the plating technique successfully deposited palladium completely and thinly. Roughly 0.05 g of palladium is deposited on each 25 cm^2 electrode at a thickness of roughly 50 nm. Auger scans are shown in Figure 4. The structures provided are thought to provide the conditions needed for cluster formation. Some preliminary electrolytic studies have been encouraging, but much more needs to be studied to understand the true promise of this new electrode design.
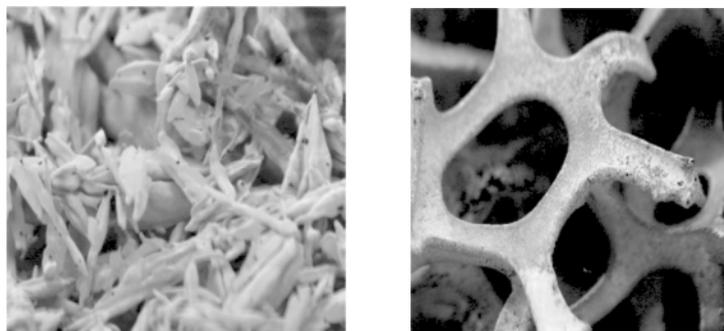

Figure 4. Auger Scan of Ni Microfelt (left) and Ni Foam (right) electrodes -White color indicates Pd-

Reaction Rate Estimates

An estimate of Cluster fusion rates in such dislocation loops at high D density follow from the well known Pycnonuclear reaction theory used for calculation of high density state fusion in astrophysics [6]. In the present case, however, the normal theory must be modified to include the effect of flow of hydrogen (deuterium) ions into the cluster site. This flow is unique to the present case of electrolytic ally driven reactions and it drastically changes the reaction rate. Initial results applying this modified Pycnonuclear theory confirms the rate strongly depends on cluster loading (i.e. on the condensation state and the dislocation geometry) and on the deuterium flux across the loop boundary flux. Results confirm that use of deuteron fluxes consistent with the thin film foil studies using CR-39 tracking foils predict rate of the same order of magnitude as indicated the experimental data. Further details about this theory will be presented in a forthcoming paper.

Implications – A Roadmap to Power Cells

If high volumetric densities of cluster sites can be created via the methods outlined earlier, a high reaction rate per cc should result given a competitive power cell. We term the electrode designed to achieve a "massive cluster electrode" (MCE) for controlled cluster reactions. Some insight to the way we hope to achieve this is illustrated in Figures 5 and 6.
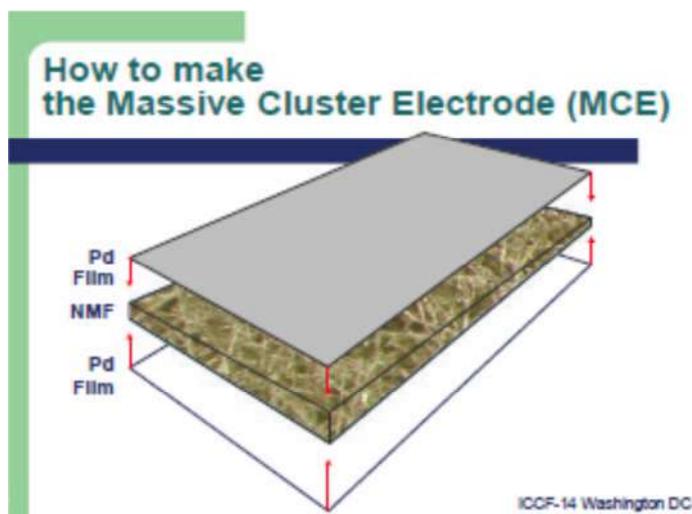

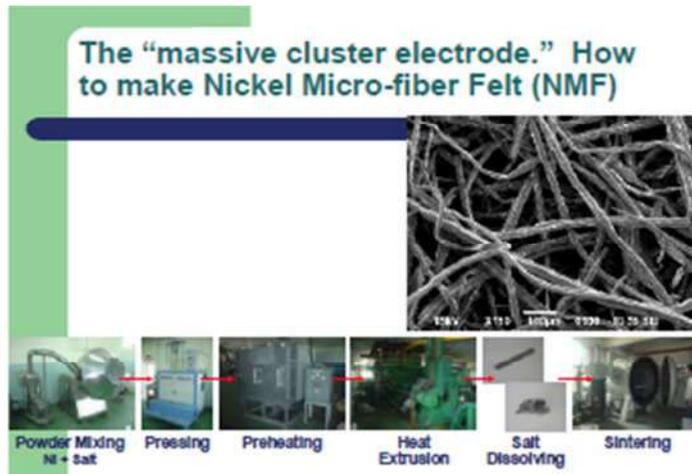**Figure 5. Illustration of construction of MCE.**

Figure 6. Construction steps for making Micro-fiber Felt (NMF) for the MCE.

The approach starts with creation of a micro-fiber felt sandwich structure as shown in Fig. 5. The MNF is a unique material that is manufactured in a multistep process outlined in Fig. 6. Palladium is then sputtered onto the MNF prior to encapsulating it into the sandwich electrode configuration. Many local defects occur at interfaces in this configuration, giving a high volumetric density of potential cluster sites. This work is currently in progress, and preliminary results to data are encouraging.

In addition to applications to LENR power systems as discussed here, a version of the Massive Cluster Electrode has a very important application in hot fusion. As suggested by the author in Ref. 5, such a structure could be used in the core of an inertial confinement fusion (ICF) target. In that application the objective is to use a laser or ion beam to compress a target, thereby compressing the clusters since the cluster deuterium density is in order of magnitude higher than cryogenic deuterium. The compressed cluster density would also exceed that possible in present cryogenic ICF targets. Since the reaction goes as the square of the density, a very large reaction rate would occur in the cluster region. In addition to power production, such conditions are of strong interest to basic understanding of fusion phenomena and astrophysics [6]. For power production the techniques would need to be extended to develop deuterium-tritium (D-T) clusters to take advantage of the high D-T fusion cross sections. Also, to reduce radiation losses development of a low-Z host material such as lithium or beryllium would be desirable.

Conclusion

This paper makes a strong case that condensed matter deuterium cluster formed in dislocation loops are one way to achieve nuclear reactive sites in LENR electrodes. The problem to date has been that the volumetric density of such cites, which is highly reactive, have a low density of sites per unit volume. Possible methods to achieve a high volumetric density of sites (i.e. achieve a massive cluster electrode (MCE) that are under study are briefly outlined. This is thought to offer an orderly "roadmap' for moving on to competitive power cells.

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