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Ultrahigh-density deuterium of Rydberg matter clusters for inertial confinement fusion targets

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Clusters of condensed deuterium of densities up to 10^{29} cm^{-3} in pores in solid oxide crystals were confirmed from time-of-flight mass spectrometry measurements. Based on these facts, a schematic outline and possible conclusions of expectable generalizations are presented which may lead to a simplification of laser driven fusion energy including new techniques for preparation of targets for application in experiments of the NIF type but also for modified fast igniter experiments using hydrogen or electron beams or side-on ignition of low compressed solid fusion fuel.

Keywords: Inertial confinement fusion; Ultra-high-density deuterium clusters; High-density solid targets; Fast ignition without pre-compression; Rydberg matter.

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Introduction

Rydberg matter was predicted and measured in gases where a static clustering of protons or deuterons to comparably high densities is generated with number densities up to 10^{23} cm^{-3} (Badiei et al. 2006). In contrast to gases, the appearance of ultra-high density clusters in crystal defects in solids were observed in several experiments where such configurations of very high density hydrogen states could be detected from SQUID measurements of magnetic response and conductivity (Lipson et al. 2005) indicating as special state with superconducting properties. These high density clusters have a long life time and with deuterons and – in contrast to protons – as being bosons which should be in a state of Bose-Einstein-Condensation (BEC) at room temperature (Miley et al. 2009,2009a).

While these clusters were measured in metals at the interface against covering oxides (Lipson et al 2005), the generation of these states within the whole volume of a metal (palladium, lithium etc.) at crystal defects, Fig. 1, (Miley et al 2007, 2008) is important. For surface states on metal oxides, the measurement of the ultra high ion densities of 10^{29} cm^{-3} was directly evident from the ion and neutral emission by laser probing. These surface states were produced involving catalytic techniques (Badiei et al 2009). The distance d between the deuterons was measured to be

$$d = 2.3 \pm .1 \text{ pm} \qquad (1)$$

compared with the theoretical value of 2.5 pm derived from the properties of inverted Rydberg matter. The energy release of the deuterons from the surface layer was measured as 630±30 eV. The difference between protons and deuterons was directly observed and the deuteron state called D(-1) is well indicating the bosonic property against the fermionic protons.

The material used in the experiments (Badiei et al 2009) as a catalyst for producing the ultra-dense deuterium is a highly porous iron oxide material similar to Fe_2O_3 doped with K, Ca and other atoms. Thus, the number of defects or adsorption sites is very high relative to a metal and the open pore volume in the material is large, of course varying with the method used to measure it. Initially the D(1) phase is formed in the pores, and it is then inverted to the ultra-dense deuterium D(-1). When probing the porous surface with the grazing incidence laser beam, fragments of the D(1) and D(-1) materials are removed from the sample surface.

Rydberg Matter is a long-lived form of matter, and the lowest possible excitation level D(1) or H(1) exists more or less permanently in the experiments (Badiei et al 2009). The clusters are not formed transiently. There is no indication that the phase D(-1) is not formed almost permanently. In the experiments both forms D(1) and D(-1) were observed simultaneously. The experiments indicate that the material changes rapidly with almost no energy difference states D(1) and D(-1).

Density of crystal defects

After it was shown that hydrogen clusters of Rydberg matter are located in crystal defects at the surface, or at interfaces, or in the volume of the metal lattice, it is interesting what densities of such defects may be available. The density of defects at the surface of solid materials was found to be of very similar value to many materials around 10^{10} per cm^2. This is known from luminescent materials for the surface traps of electrons into which the thermal mechanisms of loading or removing of electrons determines the activation energy known from the Riehl-Schön model as one of the first realization of the band level structure in semiconductors and insulators. This number could be measured also in the standard photoemission materials as the Görlich cathodes Cs_3Sb and similar compounds. Filling these traps changes the work function of the emission (Hora et al 1969) and were identified from the temperature dependence of the photoemission (Frischmuth-Hoffmann et al 1960, Hora et al 1965, 1968). Since Einstein's result of a strict linearity of the emitted electrons on the number of incident photons (Einstein 1905), it was very unexpected (Frischmuth-Hoffmann et al 1960, Hora et al. 1965, 1968, 1969) how this strict linearity was changing at very high photon densities into a sub-linearity. This was especially observed at studying the single- and the two-photon emission where at high intensities, the quantum yield changed into a square root dependence on the intensity (Boreham et al 1995) for the Görlich cathodes but also for the photoemission from silicon as measured by Malvzzi et al 1985. The mentioned standard density of surface traps was the reason that Shockley's 1950 prediction of the field effect transistor (MOS-FET) could not work until it was possible to reduce the density of the surface traps at least by a factor 100, i.e. below 10^8 per cm^2 for silicon. For the application of the ultra-dense hydrogen clusters it is interesting to increase the density. To what extend this will be possible at the surface of crystals may be a question in view of the just mentioned results.

For the generation of higher densities of defects within the bulk (volume) of crystals, several processes are well known. It is possible instead of having the 10^{29} cm^{-3} deuteron density located within one place of an atom defect, there can well defects of two or more neighboring empty places be generated as known from the x-ray generated F- and the L-centers known from color centers in crystals. It may be that this kind of centers may normally not be generated by mechanical treatment of the crystals but one may need the well known generation by radiation. This can be seen also from the sub-threshold electron beam irradiation on silicon (Hora 1983, Sari et al. 2005). When changing n- into p-conducting silicon crystals, a defect density of more than 10^{19} per cm^3 was possible well under minor increase of the volume of the crystal and generation of voids as seen from the strongly reduced thermal conductivity of these crystals (Goldsmid et al. 1984). Therefore densities n_D of defects may well be possible with the limit

$$n_D \leq 10^{-3} n_s \qquad (2)$$

where n_s is the atomic density in the host crystal for the clusters. This means that the clusters may be placed each in an average distance of about ten atoms in the host lattice. For higher densities and irreversible braking of the host crystal may happen as known from experiments (Hora 1983, Goldsmid et al 1984). But if the crystalline voids are filled with the ultra-dense clusters, their interaction with the neighbor atoms of the host crystal may reduce the stress such that the crystal will not brittle into parts.

Possible hydrogen densities in cluster filled crystals for ICF targets

After densities of 10^{29} per cm^3 deuterium atoms in the clusters have been measured and a volume concentration of defects for hosting the clusters may be achieved under stable conditions with the densities of Eq. (2) in the whole crystal of palladium or preferably of lithium (Miley et al 2008), targets for laser fusion with densities 50:50 deuterium tritium (DT) mixtures may be prepared. Taking a cluster density of 1/1000th for the clusters, the average DT density within the lithium crystal is then near 10^{26} per cm^3. This is about 2000 times the solid state of DT. It seems to be preferable to ignite such a uniform pellet by indirect drive in a NIF (Moses et al. 2008) experiment in order that the irradiated x-rays will penetrate the pellet uniformly for ignition. This would keep the advantages of indirect (x-ray) drive (Lindl 2005)) but would avoid the numerous problems of spark ignition. For this homogeneous reaction igniting uniformly in the volume of this density, the conditions of volume ignition (Hora et al. 1978; Amend et al. 2005) are automatically fulfilled (Miley et al 2005) and the gains up to 200 times more fusion energy per incident laser energy may be sufficient for energy production.

Another application would be for the modified fast ignition scheme of Nuckolls et al (2005) first disclosed in 2002 where a very intense 5 MeV electron beam is produced with a many petawatt-picosecond (PW-ps) laser pulse to ignite a large amount of modestly (12 times) solid state compressed DT for a controlled fusion reaction to produce energy with a gain of 10,000. However, this is a two step process because the electron beam to be produced by the PW-ps laser pulse at interaction can be generated only after the plasma for interaction has a more than 1000 times solid state by a preceding laser-compression. This pre-compression may in future be avoided by using the cluster target with the average 1000 times solid state DT density for generating the electron beam. This would then be a single step laser fusion energy generation as it was postulated by Dean (2008).

Another fast igniter modification is the side-on ignition of uncompressed DT or of proton-Boron11 fuel (Azizi et al. 2009). This scheme needs the application of a very unique effect discovered only lately (Hora et al 2002, 2007) by applying laser pulses with a very high contrast ratio (cut of prepulse by a factor 10^8) before the main pulse is interaction in order to avoid the otherwise always appearing relativistic self-focusing. The side-on ignition is the irradiation of laser driven highly directed plasma blocks with higher than 10^{11} Amps/cm^2 ion current densities driven (Hora et al. 2002; 2007) by nonlinear (ponderomotive) force acceleration Hora (1969). If this interaction could use cluster pellets with much higher than solid state density, the ignition condition could be further much more relaxed. Similar simplifications are possible for the proton-fast-igniter (Roth et al 2005, Hoffmann et al 2005) when using the high DT densities in lithium targets with ultrahigh density clusters.

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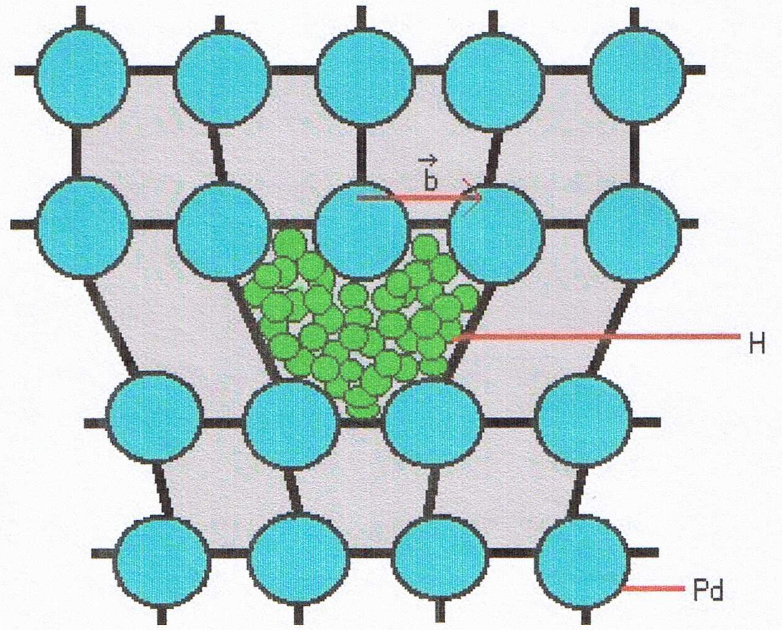
Fig. 1. Cluster with more than 100 hydrogen atoms squeezed in palladium crystal defect with superconducting properties measured by SQUIDS (Lipson et al. 2006, Miley et al. 2007) is generated, see Fig. 1 of Ref. Miley et al 2008.



Pd $(1\bar{2}1)$

$\vec{b}\,[\bar{1}01] = 2.75\,\text{Å}$