The Basics of Nuclear Fusion Reactor Using Solid Pycnodeuterium as Nuclear Fuel

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Bulk metal, in general, never absorb such abundant D/H atoms as to exceed the host metal atom density, and so, these D-atoms cannot be approachable each other at all even atomic distance of their molecule within the bulk metal. As a result, they never cause nuclear fusion within the bulk metal (ever bulk Pd). On the contrary, nano-metal, such as nano-Pd (isolated < 150 Å, embedded ≤ 50 Å in size), instantly absorbed abundant D/H atoms up to levels as high as 300% of Pd metal density. These absorbed atoms were solidified densely inside each unit cell of the host lattice as solid-state “Pycnodeuterium”/“Pycnohydrogen”. Moreover, we developed not only nano-Pd metal but also new materials which show similar behavior with nano-metal under bulk-state. In a word, peculiar bulk oxidized compound absorbed abundant D/H atoms and solid-state “Pycnodeuterium”/“Pycnohydrogen” were produced within throughout their bulk materials. Pycnodeuterium with stimulation energy easily caused intense solid-state nuclear fusion, whereas in case of Pycnohydrogen no reaction occurred. As a result, it was clarified that Pycnodeuterium is by far the best nuclear fuel compared to all other nuclear fuels just as “gaseous deuterium” against the “thermonuclear fusion”.

§1. Introduction

In order to cause solid nuclear fusion within materials, these absorbent materials of D-atoms as nuclear fuel should absorb such abundant D-atoms as to exceed at least 200% against host atoms density, just as to make Pycnodeuterium with 2 ∼ 4 D-atoms.

It is well known that the amount of D/H-atoms absorbed into the absorbent materials can be obtained using Sieverts’ law. The most important steps in the experimental method are as follows: first, keep the absorbent material inside a fixed vacuum vessel (∼10^{-7} Torr) at constant temperature for 2 ∼ 3 days, and second, inject D_2/H_2 gas into the vacuum vessel at a constant low flow rate like 20 cc/min.

Using these experimental process, the new absorption characteristics of D_2/H_2 atoms into absorbent materials were discovered, just as the advent of “incubation period” as demonstrated in Fig. 1, in which two kinds of materials were recognized: (A-material: no absorption
of $D_2/H_2$, and B-material: abundantly absorbs $D_2/H_2$). With A-material, the inner pressure $P_{in}$ (pressure inside the vacuum vessel) increases proportionally with increasing elapsed time $\tau$ during an “increasing period”. But with the B-material there is initially no increase in observed pressure with elapsed time. $P_{in}$ shows no observed change during a “constant period”, ending at point b on the horizontal axis. At the end of time period $B_0$, $\tau_*$, a saturated-state of D/H atoms in the B-metal is reached, corresponding to elapsed time $\tau = \tau_*$. Then $P_{in}$ suddenly starts to increase, and continues to increase throughout time period $B_1$, which begins at $\tau = \tau_*$. In other words, in B-material, two kinds of time periods in measured pressure $P_{in}$ were observed (“constant period” $B_0$ and “increasing period” $B_1$). We use the name “incubation period” for the “constant period” with no increase in observed $P_{in}$ above the zero reading. The incubation period extends from $\tau = \tau_0$ (starting point) to $\tau = \tau_*$ (b-point). Moreover B-material is also characterized by a large release of chemical energy during the first period, as shown in curve C. The heat release results from the exothermic absorption of D-atoms. The heat release corresponds to $\sim 10$ kcal/mol throughout the incubation period. As a result, the exact amount of absorbed D-atoms is easily calculated based on incubation period observation. The observations showed that developed new absorbent materials correspond to B-material, whereas the bulk state of all metals corresponds to A-material.

§2. Experiment

2.1. Absorption experiment (importance of “incubation period”)

The most important information gained from the absorption experiments using Pd black inside DS-cathodes was the existence of an incubation period, as described in detail in the introduction. We have developed new materials with long incubation periods (as long as possible).

In one of the experiments, nano-Pd particles of 50 Å size are embedded inside a matrix of ZrO$_2$. In Figs. 3 and 4, the sample powder is designated ZrO$_2$·Pd$^\circ$. It is derived from an oxidized amorphous alloy of Zr$_{65}$Pd$_{35}$. ZrO$_2$ by itself behaves as A-material, while nano-Pd particles Pd$^\circ$ correspond to B-material. The nano-Pd easily absorbs the average 3D-atoms per host Pd$^\circ$ atom. These D-atoms are solidified as an ultra high density deuterium-lump (“Pycnodeuterium”) inside each octahedral space within unit cell of the Pd$^\circ$ host lattice. These “Pycnodeuterium” are dispersed so as to form a “metallic deuterium lattice”, with body-centered cuboctahedron structure as shown in Fig. 2.¹)

¹)
ZrO$_2$·Pd$^\circ$ as one of the new materials, and moreover we developed bulk state new material with the goal of achieving long incubation periods. For instance, new peculiar oxidized bulk composite such as a Zr-Ni-O system designated Zr$_3$NiO$_2$·NiO (shortly, Zr$^*$·NiO or Zr$^*$; because Zr$^*$ $\gg$ NiO in weight, then Zr$^*$ $\equiv$ Zr$_3$NiO) as shown in Fig. 3 was developed. In this case, in order to realize a long incubation periods, we had to create bulk composite material Zr$^*$. Bulk-state metals never achieve long incubation periods, but bulk oxidized composite can absorb abundant D/H atoms. This composite is no metal and the whole of Zr$^*$ is one crystal lattice of oxidized compound as “bulk-state”, on the contrary nano-metal Pd$^\circ$ is only a part of the sample. This is the biggest difference between nano Pd$^\circ$ and bulk Zr$^*$, but when the both samples absorb D/H atoms into their lattice, their constitutional host atoms work with similar mechanism as follows; each individual host atom of the nano-metal Pd$^\circ$ and each sub-unit of the bulk oxidized lattice of Zr$^*$ releases strain energy stored within their atomic structure.

In the same way as illustrated in Fig. 1, we investigated the characteristics of the following sample powders, designated in Fig. 4 by their 4 kinds of materials: Zr$^*$, Pd$^\circ$, Pd black (Pd$^\bullet$) and bulk metal Pd wire, designated Pd$^\circ$. The wire was cut into pieces 0.2 mm in diameter and 2 mm in length. Each sample had a 3-gram weight. Results are shown in Fig. 4.

This diagram is one of the most important results in our chain of experiments. When the materials were used with the same total weight, bulk oxidized composite Zr$^*$ absorbed the highest quantity of D-atoms, as indicated by the longest incubation period. It also generated the largest chemical reaction energy. In contrast, with bulk Pd$^\circ$ almost nothing occurred. The test materials shown in Fig. 4 are listed in order of decreasing

![Figure 3: Relation between sample powders of ZrO$_2$·Pd$^\circ$ and Zr$^*$·NiO.](image)

![Figure 4: Deuterium absorption characteristics of sample powders; Zr$_3$NiO$_2$·NiO, ZrO$_2$·Pd(ZrO$_2$·Pd$^\circ$), Pd black and bulk Pd.](image)
lengths of their incubation periods and in order of increasing amounts of D-atoms absorbed as measured by integrated released chemical reaction energy. The sample order is:

$$\text{Zr}_3\text{NiO} (\text{Zr}^*) > \text{ZrO}_2 \cdot \text{Pd} (\text{Pd}^\circ) > \text{Pd black} (\text{Pd}^\bullet) > \text{bulk Pd} (\text{Pd}^\circ).$$

(2.1)

This listing order is based on the equal 3-gram weights. Here, although $\text{Zr}^* = \text{Pd}^\bullet = \text{Pd}^\circ = 3$ gram in weight, $\text{ZrO}_2 \approx 2$ gram, $\text{Pd}^\circ \approx 1$ gram in 3gr $\text{ZrO}_2 \cdot \text{Pd}$ which was made by oxidizing bulk amorphous alloy $\text{Zr}_{65}\text{Pd}_{35}$, and although $\text{ZrO}_2$ cannot absorb, $\text{Pd}^\circ (=\text{nano-Pd})$ absorbs abundant D/H atoms. The $\text{Pd}^\circ$ contributes about one third of the weight of the $\text{ZrO}_2 \cdot \text{Pd}$, whereas the $\text{Zr}^*$ and $\text{Pd}^\circ$ might be expected to contribute the majority or all of the weight in their respective powder samples. In reference to the active nano-metal content, the $\text{Pd}^\circ$ might be the most absorbent powder component. However, assemblages of nano-particles cannot exist when the nano-metal components contact each other. The particles instantly change into bulk-state metal with the low absorption properties described in the introduction. This makes the nano-metal fraction uncertain. The order of Eq. (2.1), based on the same weight of powder sample, avoids this uncertainty. It indicates that abundant “Pycnodeuterium” is formed with both $\text{Zr}^*$ and $\text{Pd}^\circ$.

In the following section we show that solid nuclear fusion reactions occur when “Pycnodeuterium” is present in response to stimulation energy. However, in bulk $\text{Pd}^\circ$ nothing happens. From this behavior, we understand that the great important event is formation of “Pycnodeuterium”.

2.2. Reactor experiment (importance of “Pycnodeuterium”)

We developed the concept of a solid nuclear fusion reactor using solid Pycnodeuterium as fuel, as shown in Fig. 5. The left side illustrates the principle of the Laser Welding fusion reactor, and the right side diagram illustrates the principle of the Sonoimplantation solid fusion reactor. In the Laser Welding fusion reactor, shown in the left diagram, the sample holder is an inverted triangular ditch which was machined into a solid stainless steel rod parallel to its center axis. The rod was 3 cm in
A 3-gram sample of powder was dispersed along the bottom of the ditch, which extended over 10 cm. The sample holder was inserted into a quartz glass cylinder, and the inner air was evacuated so as to maintain a vacuum of $10^{-7}$ Torr extended over 2 days at 130 °C. After that, D$_2$ gas was injected into the quartz cylinder at a constant flow rate of 20 cc/min until the inner pressure of D$_2$ gas built up to 10 atm. The D$_2$ gas inflow was absorbed as D-atoms into the sample powder and also served as a “reactor working gas”. Then, laser stimulation energy was supplied for a period of time to the solid Pycnodeuterium fuel by the usual Laser Welding process. The upper part of the diagram shows the laser wave form, which is a repeated rectangular pulse with a pulse width of 2 msec, height of 7.5 K watt, and pulse energy of 15 Joule/pulse. The pulse repetition rate was 20 pps and average power was 300 watt. The energy stimulation process lasted for 10 seconds. During this time 200 light pulses were delivered along the 10-cm ditch.

Figure 6 shows micrographs of powder “Before” and “After” the Laser stimulation of nano-Pd particles (Pd$^\odot$) using D$_2$/H$_2$ gas as the reactor working gas. Left top side Photo [A] shows the “Before” sample condition, that is, it shows the original powder of ZrO$_2$-Pd in the crushed condition of oxidized Zr$_{65}$Pd$_{35}$. Photo [B] is an electron micrograph of [A], which shows nano-Pd particles Pd$^\odot$ dispersed within a matrix of ZrO$_2$ for the “Before” sample. Photo [C] and Photo [D] are electron micrographs which show the “After” condition, that is, after using the Laser Welding process. Both Photo [C] and Photo [D] are to be compared with the “Before” condition of Photo [B]. Photo [C] clearly shows that the ZrO$_2$ matrix and nano-Pd particles were dramatically melted, creating spherical shapes with various kinds of size, and separated from each other. In this photograph, black balls and translucent balls can be seen, with nano-Pd particles dispersed inside matrix ZrO$_2$, with both instantly changed at the same time into bulk Pd and ZrO$_2$, respectively. Moreover, we can see many black balls of various sizes, even inside the large translucent ZrO$_2$ balls.

These dramatic changes resulted from Solid Pycnodeuterium nuclear fusion. Photo [D] is substantially different from the Photo [C], even though the same process was used in both experiments. Photo [D] shows sharp edges and no balls. In Photo [D] “Pycnohydrogen” was used instead of “Pycnodeuterium”. That is to say, the working gas was H$_2$ instead of D$_2$ gas, and it never caused nuclear fusion.
§3. Mixed gas studies

Based on this experiment, we have explored two important issues: 1. What kind of working gas is the best? 2. What kind of stimulation beam energy is the best to excite Pycnodeuterium? Choices include the laser, electron, plasma, neutron, and sono beam, and so on. At present we are still investigating these questions. We are testing mixed gases, not only pure D₂, but mixtures such as D₂ + He gas. As shown in Fig. 7, using pure D₂ gas and mixed D₂ + He gas in conjunction with a particular composite Zr*, evident differences appeared in D-absorption characteristics. For the same end pressure, the “constant period” was shorter with the mixed gas than with the pure D₂ gas. Another difference was a slightly lower chemical reaction rate and a slightly longer reaction period with the mixed gas. This made it necessary to raise the inner pressure in the early stages with the mixed gas. Despite these differences, the total chemical reaction energy was the same with both working gases.

These results reveal the difficulty of D-absorption into Zr* particles from a mixed gas as compared with pure D₂ gas. We conclude that D₂ and ⁴He in the mixed gas are separated at the surface of the particles. D₂ gas can easily enter into composite Zr* as D-atoms until saturation. But He atoms can not enter, so they remain at the surface, and disturb the D₂ gas coming to contact at the surface. Until saturation of D-atoms, this event requires the use of a higher inner pressure compared with pure D₂ gas when using a mixed gas.

This conclusion was very important, and prompted a new idea, which is displayed in Fig. 8. Namely, as shown in left side diagram [A], use of pure D₂ working gas results in an ultrahigh density of D₂ molecules at the surface of the sample particles when they are saturated with D atoms. These molecules are called “boundary molecules”. When using mixed D₂ + He gas, as shown in the right side diagram [B], there is a corresponding ultrahigh density of He atoms concentrated at the surface of the sample particles. We called these atoms “boundary atoms”. It is emphasized that the total amount of D absorbed inside each sample particle is the same for the two working gases. This is very important to understand in order to follow our thinking regarding the new experiment results. For instance, using pure D₂ working gas, the incident
stimulation energy first excites “boundary molecules” and also produces excited D atoms coming from the dissociated D₂ molecules. In other words, the incident energy changes into three kinds of “boundary” energy: dissociation energy in the form of dissociated D₂ molecules, excitation energy in the form of excited D atoms, and energy delivered directly to the surface of the composite particles. In contrast, when using the mixed working gas D₂ + He, the incident energy changes into only two kinds of “boundary” energy: excitation energy in the form of excited He, which is excited to a relatively high excitation level, and energy delivered directly to the surface of the composite particles. As a result, the excited He compared with the excited D-atoms has a strong possibly of effectively exciting Pycnodeuterium with considerably higher energy and larger amount. Therefore, it was concluded that use of a mixed working gas compared pure D₂ gas has a greater expectation for generating strong Pycnodeuterium nuclear fusion.

Figure 9 shows the results of the Laser Welding nuclear fusion studies. The bottom side diagrams show “absorption characteristics” of the working gases absorbed into the sample powders. The left side diagram Gas [A] shows the absorptions of pure D₂ gas and pure H₂ gas into Pd particles, respectively. The right side diagram Gas [B] shows the absorptions of two D₂ + He gas mixtures, with 10³ and 10⁴ ppm He, respectively, into 4 kinds of sample powder: Zr* from Zr₃NiO, Pd⊙ from ZrO₂·Pd, Pd black, and bulk Pd. All powder samples were 3 grams in weight.

The upper diagrams [A₀] and [B₀] in Fig. 9 show the amounts of ⁴He generated as a result of using the Laser Welding stimulation process, using Gas [A] and Gas [B], respectively. The vertical axis indicates “Generated He”, represented by the symbol ΔHe (“After” - “Before”), which is the difference in the amount of He “After” and “Before” Laser Welding stimulation. The calibration scale for the mass spectrometer helium data is based on a helium signal using an air sample, which contains 5.2 ppm ⁴He. In addition, when D₂ + He mixed gases are used, the “Generated He” is quantified by another symbol R_{He}, which is the “After”/“Before” ⁴He signal ratio. The measured “Generated He ratios” are printed inside the blue circles in diagram [B₀], which is the upper-right part of Fig. 9. The horizontal axis is drawn at the “Before” condition, which corresponds to ΔHe =~0

Fig. 9. Experimental conditions and results in Laser welding Nuclear Fusion using reactant sample.
The results of studies using pure D2 gas in conjunction with powder samples Pd⊙ from ZrO2-Pd are shown in diagram [A0], which is the upper-left part of Fig. 9. We concluded that in one test 100 ppm of 4He was generated by the Laser Welding stimulation. The data for a corresponding study using pure H2 with a Pd⊙ sample powder showed no generated 4He.

The results of the studies using “Mixed gas” and various powder samples are shown in diagram [B0], which is the upper right side diagram of Fig. 9. Powder samples tested using “Mixed gas” were: Zr* from Zr3NiO, Pd⊙ from ZrO2·Pd, Pd from Pd black, and bulk Pd. Zr* and Pd⊙ caused abundant 4He, such as around 105 ppm. But in spite of using the same conditions, much less 4He was generated in Pd black and no 4He was generated in bulk Pd.

The Laser Welding process was developed by us in 1966, and was the first such process in the world.

§4. Sonoimplantation nuclear fusion

The following results of sonoimplantation nuclear fusion are presented. We introduced the term of “sonoimplantation”,2) and published in Proc. Japan Acad. 4 times beginning in 1998, and 2 times in Appl. Phys. Lett. (USA) and in Proc. ICCF9 last year. The key point in sonoimplantation is that all kinds of gaseous atoms can be easily implanted into all kinds of metal particles using the sonoimplantation effect. Figure 5 [B] illustrates the principle of the sonoimplantation solid fusion reactor. Marks 1-4 identify a closed vessel, reactant sample, ultrasonic vibrator, and sonic transfer medium D2O or H2O for the ultrasonic beam. Marks 5-7 identify pipes for evacuation, reactor working gas injection, and liquid injection of D2O and H2O. To begin a test, a reactant sample is placed on the bottom of the closed vessel. Then the inner air is evacuated so as to keep the pressure below 10−7 Torr for a period of 2 ∼ 3 days at 150 °C. After that, pure D2 gas is injected into the closed vessel through pipe 6 with a fixed flow rate $V_G$ (= 20 cc/min) until the inner pressure $P_{in}$, reaches 10 atm. Then, D2O/H2O liquid is injected by pipe 7 into the closed vessel. In the
tests providing the data shown in Fig. 10, sono-power of 300 watt at 19 kHz was used for about one hour and directed against samples of Pd powder and Pd black, respectively. Mixed gases, D$_2$ + 400, 10$^3$, or 10$^4$ ppm He, were used with Pd and Pd black for bottom-left chart labeled “Gas [C]”. Mixed gases, H$_2$ + 400 ppm He and H$_2$ + 10$^4$ ppm He, were used for bottom-right chart labeled “Gas [D]”. These gases were injected into the reactor vessel in the same way as employed in the Laser Welding process.

Again referring to Fig. 10, the data displayed in the upper-left side chart [C$_0$] tested Gas [C] in conjunction with Pd-black, and also in conjunction with several powder samples Pd$^{\odot}$ from ZrO$_2$·Pd. Tests with the D$_2$ + He mixed gases showed “Generated He ratios” as high as almost 30, relative to the initially present He. Tests with the H$_2$ + He mixed gases were also carried out, and also a test with D$_2$ gas mixed with 7% H$_2$. When the mixtures containing H$_2$ were used, no “Generated He” was detected, as shown in upper right side [D$_0$].

### §5. Conclusions

1) Pycnohydrogen (ultrahigh density of hydrogen-lumps) never causes the nuclear fusion reaction.
2) Bulk metal never causes Pycnodeuterium, hence never causes the fusion reaction.
3) If materials easily form solid Pycnodeuterium, then they can cause strong solid nuclear fusion.
4) Solid Pycnodeuterium is by far the most excellent fuel for nuclear fusion, as compared with gaseous deuterium as used in thermonuclear fusion. Thermonuclear fusion requires an ultra high temperature plasma. Because a high temperature plasma requires high temperature, low density electrons, there is an excessively large “Debye-shielding length” and no neutralizing zone. The D-ion space charge becomes too large, just as in the vacuum state.

At the present, two methods using laser stimulation energy are used to cause thermonuclear reaction, as shown in Fig. 11. One is to use an extremely high power pulsed laser “implosion” system, which is well known in general. Results obtained by the newest system were described in Nature last year. Results corresponding to the highest reported input power are shown in a “parenthesis” in the notice in Fig. 11. These data were obtained using an input pulse with a pulse power of 10$^{19}$ watt/50-ps. The plasma temperature was 10$^4$ eV and the number of generated particles was 10$^{13}$ per pulse. As shown in a numerical value at the front of above parenthesis, using an input pulse with pulse power of 10$^{15}$ watt over a 1-ps period, the plasma temperature was 10$^3$ eV and the number of generated particles was 10$^5$/pulse. This is the latest report for thermonuclear fusion using “gaseous deuterium” as fuel. In contrast, there is the Laser Welding nuclear fusion system using “solid Pycnodeuterium” as fuel. Our Laser stimulation system used only 300 watt and generated about 10$^{19}$ to 10$^{20}$ particles per 10 seconds. It is concluded that “solid Pycnodeuterium” with stimulation energy is by far the more excellent fusion fuel as compared with “gaseous deuterium” as used in “thermonuclear fusion”. It is, therefore considered worth while to test the “solid fuel” against the “gaseous fuel” using various stimulation energy
systems, including the laser system. We think such testing is very important.

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