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BRIEF EXPLANATION OF EXPERIMENTAL DATA SET ON EXCESS HEAT AND NUCLEAR TRANSMUTATION IN MULTIPLLY NANOCOATED NI WIRE*

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Abstract

Experimental data of excess heat generation and nuclear transmutation obtained in Ni wire multiplly nano-coated with Pd and a compound of B, Sr, Ba and Th at up to 900 degC have been analyzed using the TNCF model.

The Ni wire is 50 μm in diameter and 82 cm long. The coating is made of Pd and the compound about 50 times resulting in a surface layer of about one μm thick. The maximum excess energy Q_{max} is 1800 W/g of the Ni wire. There have occurred various nuclear transmutations. The most notable results are enumerated as follows: (1) Elements Ti, Cr, Co, As, Ir, and Tl have increased. (2) B, Sr, Pd and Ba have decreased. (3) Fe and Ni have not showed remarkable change. (4) In the case of B, Sr and Ba, the rates of the decrease are larger for lighter isotopes. (5) ${}^{10}{}_{5}B/{}^{11}{}_{5}B$ ratio decreased over 14%. (6) ${}^{105}{}_{46}Pd$ decreased about 5% and ${}^{102}{}_{46}Pd$ increased about 9%.

These data have been analyzed using the TNCF model successfully applied for explanation of various experimental data sets over the past 15 years. We can estimate the parameter of the model n_n using the data for ${}^{10}{}_{5}B$ and ${}^{105}{}_{46}Pd$ as follows; $n_n = 1.3 \times 10^9$ cm^{-3} (by the decrease of ${}^{10}{}_{5}B$) and $n_n = 2.5 \times 10^{11}$ cm^{-3} (by the decrease of ${}^{105}{}_{46}Pd$). These values show the situation in the experiment belong to a range of fairly large value of the parameter where we can expect the nuclear reactions by a single neutron and also a n-p cluster.

The excess heat generation of 1800 W/g at its maximum has been investigated using the value of n_n estimated above and a formula for the excess energy is induced. Assuming the surface layer of 1 μm thick is made of Pd only, for illustrative purposes, we have obtained Q_{av} about 1% of the observed maximum one. If the average value of the excess energy is about 10% of the maximum, the discrepancy is about one order of magnitude. If we know the correct composition of the surface layer, the calculated value of Q_{av} will increase a little.

The nuclear transmutation of several elements confirmed by the experiment is qualitatively explained assuming the single neutron absorption by elements in the surface layer. The decrease of Ru might be explained by a single *n-p* cluster absorption.

1. Introduction

The cold fusion phenomenon (CFP), i.e. low energy nuclear reactions in solids with high density hydrogen isotopes at near room-temperature in a non-equilibrium condition including ambient radiations, has been observed in various materials composed of mainly transition metals and hydrogen isotopes. The phenomenon is characterized by extraordinary excess energy inexplicable by ordinary chemical and physical processes possible to occur in systems at temperatures around ordinary environment without specific acceleration mechanism. This is the reason some nuclear reactions should be relevant to the cause of the CFP. Based on the experimental data sets obtained until now, the nuclear reactions in CF materials are supposed to occur at boundary regions between a host material (e.g. NiH_x wire) and a guest material (e.g. layer composed of multiplly coated nano-films of Pd and (B, Sr, Ba, Th) compound). The guest material is formed automatically in the surface/boundary regions of a host material unintentionally on the surface of cathode in an electrolytic experiment or on the surface of electrode in a plasma discharge experiment [1 – 2]. In some experiments, the guest material is intentionally formed on the host material by artificial manner; coating alien elements on a metal surface or depositing elements on a cathode surface. There are such several examples of artificially formed guest materials as those of Yamaguchi [3], Patterson [4], Szpak [5], Iwamura [6], Celani [7] among others.

The different role of the host and guest materials is speculated as follows from our point of view. The role of the host material (NiH_x, PdD_x, TiD_x, - - -) composed of an interlaced lattices of host metal and occluded hydrogen isotope is to form the cf-matter with a dense neutron liquid.

On the other hand, the guest material composed of irregular array of elements gives an active region for the nuclear reaction resulting in the cold fusion phenomenon (CFP). The neutron Bloch wave in the host material reacts with alien nuclei disturbing regularity of the host material. This is the reason that the nuclear reaction occurs at surface/boundary regions of the host and a guest material.

The alien nuclei in the guest material become agents of the nuclear reactions resulting in the cold fusion phenomenon, i.e. nuclear reactions in transition-metal hydrides and deuterides in ambient radiation at room temperature or at even higher temperatures.

The interesting experimental data obtained in multiplly nanocoated Ni wire are investigated from this point of view to give qualitative and semi-quantitative explanation of their typical results.

2. Experimental

In the experiment by Celani et al. [7], the sample is a Ni wire (ϕ = 50 μm and length of 82 cm, mass of 14 mg) multiplly nano-coated (final thickness ≈ 1 μm) by Pd and a compound including B, Sr, Ba, and Th by 50 times successive coating. A schematic section of the nanocoated Ni wire is shown in Fig. 1. We can see the system as composed of two parts; the central part is consist of NiH_x forming the host material of the system and the outer part is consist of stratified fifty thin layers of different components including Pd, B, Sr, Ba, Th, H (D). In several experiments to the active gas (H_2 and/or D_2) was added Ar (20-50%) in order to decrease the thermal conductivity and, as consequence, increase the wire temperature at a constant applied electrical power.

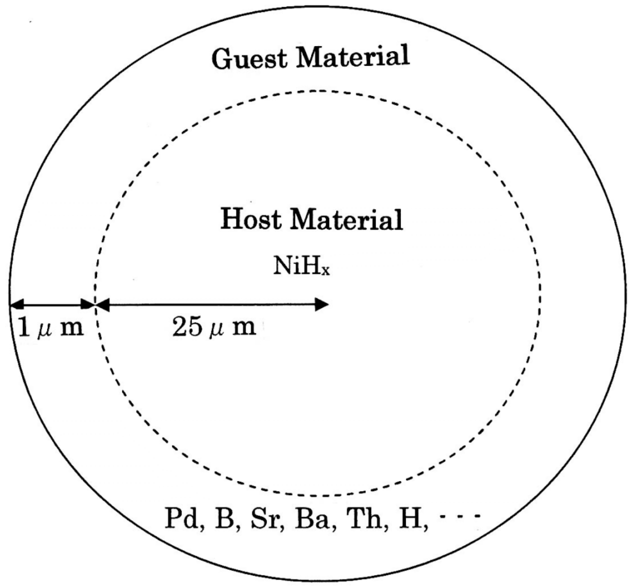

Fig. 1 Schematic cross section of the multiplly nanocoated Ni wire.

The Ni wire nanocoated, after several loading-deloading and thermal high temperatures cycles, at very high temperatures (900°C) and under electromigration current of the order of 40-45 kA/cm^2, showed an excess power, in respect to a similar "virgin" wire with the same applied power (148W), of about 26W. The (main) gas atmosphere was hydrogen added of argon (ratio 60/40) at a pressure of 6 atm at room temperature.

Some compositional and isotopic anomalies were detected by PIXE and ICP-MS analysis. Some of them are so large that it is difficult to think they can arise from systematic or statistic errors. As a general trend, by ICP-MS analysis, in the case of elements with several isotopes (B, Sr, Ba), the rate of decreasing is larger for lighter isotopes. Such effect is clearly evident with B_{10}/B_{11} ratio: it decreased of over 14%. A special situation happened for Pd coating: it seems reduced (about 5%) Mass 105 (isotopic abundance 22.3%) and largely (about 9%) increased Mass 102 (isotopic abundance 1%).

In Fig.2 are shown the results of analysis by PIXE [7].

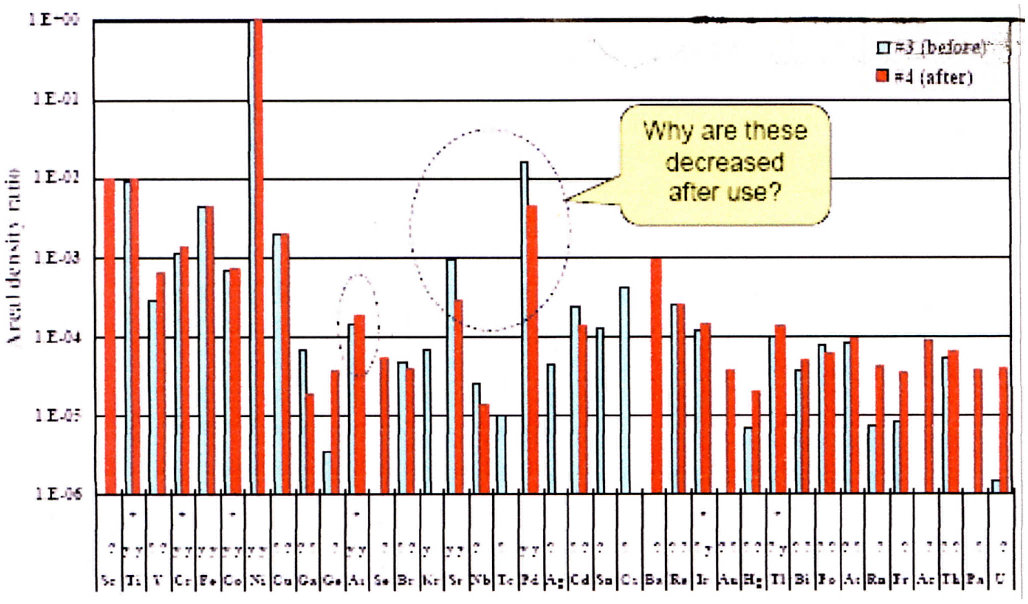

Fig. 2 Change of elemental composition before and after H_2 gas loading by PIXE.

3. Theoretical investigation

According to the recipe of the TNCF model [Kozima Development, Science,], excess energy and nuclear products may be generated by all nuclear reactions occurring in the sample as a whole, mainly in the guest material.

3.1 Nuclear Reactions between Trapped Neutrons and Nuclei in the Guest Material

The trapped neutron in the TNCF model exists in the host material and its density is vastly intensified at surface/boundary regions where is the guest materials.

Number N_{nX} of nuclear transmutation (NT) of a nucleus X by absorption of a neutron in the TNCF model;

$$N_{nX} = 0.35 n_n v_n n_X \sigma_{nX} V\tau \qquad (1)$$

where n_n and v_n are the number density and thermal velocity of the trapped neutrons in the model, n_X is the number density of the nucleus X in the active volume V where the transmutation occurs in a time τ, and σ_{nX} is the absorption cross section of a thermal neutron by the nucleus X ([1] Section 11.1, [2] Sec. 3.2).

It should be noticed at first that we have determined the parameters n_n using many experimental data sets and tabulated them in Tables 11.2 and 11.3 of [1] (and Tables 2.2 and 2.3 of [2]) . The values have been determined as tabulated there and are in the range 10^8 to 10^{11} cm^{-3}.

Numerical values in the equation (1):

$v_n = 2.20 \times 10^5$ cm/s (at room temperature)

$n_{Pd} = 6.88 \times 10^{22}$ cm^{-3} (assuming Pd lattice)

$\sigma_{nPd105} = 2.025 \times 10$ b $= 2.025 \times 10^{-23}$ cm^2 (for ^{105}Pd and thermal neutron)

$\sigma_{nB10} = 3.837 \times 10^3$ b $= 3.837 \times 10^{-21}$ cm^2 (for ^{10}B and thermal neutron)
The cross sections of neutron capture increase, like 1/E in log-log scale, at lower energies. In principle, the energy of neutron can be even lower than thermal.
The Eq. (2.1) for the number of reactions in a volume V and time τ is rewritten as follows to make the meaning of each term clearer;

$$N_{nX} = (0.35 n_n v_n)\,(n_X \sigma_{nX})(V\tau). \tag{2}$$

The quantity in the first bracket relates to the cf-matter in the host material, the second to the agent element X, the third to the experimental condition. The relevant quantity of the isotope $^A{}_Z$X of an element X in the sample is $\rho_{XA}\sigma_{XA}$ where ρ_{XA} is the abundance in percent and σ_{XA} is the cross section for a neutron absorption of the isotope $^A{}_Z$X. If we know the density n_X of the element X in the sample, we obtain the relevant quantity ($n_X\sigma_{nX}$) of the element X in Eq. (2) by summing up $\rho_{XA}\sigma_{XA}$ over A and multiplying by n_X;

$$N_{nX} = (0.35 n_n v_n)\, n_X \Sigma_A \rho_{XA}\sigma_{XA}\, V\tau. \tag{3}$$

To calculate excess heat generated by nuclear reactions in the sample, we need another modification of the equation. If a reaction between a thermal neutron and a nucleus X generate excess energy q_X, the total excess energy Q_X in a unit volume and unit time is given by the number N_{nX} of reactions in the volume V and time τ multiplied by q_X and divided by $V\tau$;

$$Q_X = Q_X(V, \tau)/V\tau = N_{nX}\, q_X \tag{4}$$

When there are isotopes $^A{}_Z$X of the element X with abundance ρ_{XA}, the corresponding energy Q_A by an isotope $^A{}_Z$X generating q_{XA} is given as follows;

$$Q_A = 0.35 n_n v_n\, n_X \rho_{XA}\sigma_{XA} q_{XA}$$

And then, the total energy Q_X by the element X with a density n_X in a unit volume and time is given by a summation of Q_A over A;

$$Q_X = \Sigma_A Q_A = 0.35 n_n v_n\, n_X \Sigma_A \rho_{XA}\sigma_{XA} q_{XA}. \tag{5}$$

If there are several agent nuclei X, X', - - - in the active region, the total excess energy Q generated in a sample in unit volume and time is given by summation of the Q_X over X;

$$Q = \Sigma_X Q_X = 0.35 n_n v_n \Sigma_X n_X \Sigma_A \rho_{XA}\sigma_{XA} q_{XA}. \tag{6}$$

3.2 Explanation of Experimental Data by the TNCF Model

Qualitative explanation of experimental facts explained in Section 2 is naturally deduced from the characteristics of the TNCF model. Brief explanation is given as follows.

3.2.1 Decrease of B_{10}/B_{11} ratio and $^{105}{}_{46}$Pd.

The change of a nucleus $^A{}_Z$X of an element X is governed by a quantity ($n_X\sigma_{nX}$) of Eq. (3).

Looking into the table of nuclei, we know this quantity ($n_X \sigma_{nX}$) for $^{10}{}_{5}B$ (B_{10}) and $^{105}{}_{46}Pd$ is very large compared to other isotopes of these elements; 7.59×10^3 and 4.522, respectively. The larger the value ($n_X \sigma_{nX}$) of a nucleus $^{A}{}_{Z}X$ is, the more nuclei transmute to the isotope with a higher mass number $^{A+1}{}_{Z}X$. Therefore, $^{10}{}_{5}B$ and $^{105}{}_{46}Pd$ decrease remarkably compared to other isotopes.

The decrease of $^{105}{}_{46}Pd$ by 5% in one month is used to calculate the parameter n_n in Eq. (1) to give the value for this case;

$$n_n = 2.5 \times 10^{11}\ \mathrm{cm}^{-3}. \tag{7}$$

This value is in the upper level of n_n determined hitherto and we may expect occurrence of nuclear reactions mediated by the neutron-proton cluster $^{4}{}_{2}\delta$ in this system.

3.2.2 General Tendency of Isotope Change

It is noticed that the rate of decreasing is larger for lighter isotopes in the case of elements with several isotopes (B, Sr, Ba). This tendency is explained by the same reasoning given above for the decrease of $^{10}{}_{5}B$ and $^{105}{}_{46}Pd$. The nuclear transmutation governed by the quantity ($n_X \sigma_{nX}$) shifts isotopes to the ones with a higher mass number by one.

3.2.3 Decrease of Sr and Pd, and increase of As.

Looking into the table of isotopes, we notice that Sr and Pd have many isotopes which decay into other elements after absorption of single neutron. For instance, we can write down several such reactions as follows;

$$n + {}^{84}{}_{38}\mathrm{Sr} \rightarrow {}^{85}{}_{38}\mathrm{Sr}^* \rightarrow {}^{85}{}_{37}\mathrm{Rb} - e^-,\ Q = 1.07\ \mathrm{MeV},\ (\tau = 64.84\ \mathrm{d}) \tag{8}$$

$$n + {}^{88}{}_{38}\mathrm{Sr} \rightarrow {}^{89}{}_{38}\mathrm{Sr}^* \rightarrow {}^{89}{}_{39}\mathrm{Y} + e^- + \underline{\nu}_e,\ Q = 1.5\ \mathrm{MeV},\ (\tau = 50.53\ \mathrm{d}) \tag{9}$$

$$n + {}^{102}{}_{46}\mathrm{Pd} \rightarrow {}^{103}{}_{46}\mathrm{Pd}^* \rightarrow {}^{103}{}_{45}\mathrm{Rh} - e^-,\ Q = 0.543\ \mathrm{MeV},\ (\tau = 16.99\ \mathrm{d}) \tag{10}$$

$$n + {}^{106}{}_{46}\mathrm{Pd} \rightarrow {}^{107}{}_{46}\mathrm{Pd}^* \rightarrow {}^{107}{}_{47}\mathrm{Ag} + e^- + \underline{\nu}_e,\ Q = 0.033\ \mathrm{MeV},\ (\tau = 6.5 \times 10^6\ \mathrm{y}) \tag{11}$$

$$n + {}^{108}{}_{46}\mathrm{Pd} \rightarrow {}^{109}{}_{46}\mathrm{Pd}^* \rightarrow {}^{109}{}_{47}\mathrm{Ag} + e^- + \underline{\nu}_e,\ Q = 1.12\ \mathrm{MeV},\ (\tau = 13.7\ \mathrm{h}) \tag{12}$$

These examples show clearly possible decrease of Sr and Pd by the mechanism of single neutron absorption followed by decay to another element.

On the other hand, the increase of As is explained by absorption of a neutron-proton cluster $^{4}{}_{2}\delta$ even if the decrease of Ge is not confirmed in the experiment;

$$^{4}{}_{2}\delta + {}^{71}{}_{31}\mathrm{Ge} \rightarrow {}^{75}{}_{33}\mathrm{As}. \qquad (Q = ?,\ \tau = ?) \tag{13}$$

3.2.4 Excess Energy Generation

The reaction equations (8) – (12) give us possible source of excess energy by nuclear reactions between agent nuclei in the guest material and the trapped neutrons. Summing up excess energy generated in possible reactions, we can calculate total excess energy produced in the sample by the assumed mechanism of the TNCF model. The effectiveness of the model will be justified by successive explanation of the nuclear transmutation and excess energy generation adjusting the single parameter n_n.

The excess energy is expressed as follows in this model for a guest material composed of Pd, Ni, B, Sr, Ba, Th, H and Ar;

$$Q\,(\mathrm{MeV}) = 0.77 \times 10^5\, n_n \{0.05\, n_B + 0.01\, n_{Sr} + 0.62\, n_{Ba} + 49.65 n_{Th} + 2.67 n_{Pd} + 3.67 n_{Ni} + (0.737\rho_1 + 3.44 \times 10^{-3}\, \rho_2)\, n_{H} + 1.63\, n_{Ar}\} \times 10^{-24}. \qquad (14)$$

n_X is the number density in cm^{-3} of an element X, and ρ_1 and ρ_2 are ratios of protium and deuterium in the guest material, respectively.

Illustrative calculation of this value Q for a surface layer, or a guest material, on the Ni wire is made for a hypothetical composition PdH and the value of n_n given in Eq. (9). The result is given as

$$Q_{th} = 0.09 \text{ W} \qquad (15)$$

for the sample with the same size used in the experiment [7]. This value should be taken as an average value of the excess energy expected in the hypothetical system with the same sample size to the one in the experiment [7].

The maximum excess energy measured in the experiment is rewritten as follows;

$$Q_{\mathrm{ex,\,max}} = 25.2 \text{ W}. \qquad (16)$$

If we know the average value of the excess energy observed in the experiment, the comparison becomes more meaningful. It may be possible to assume the average value is one order of magnitude smaller than the maximum (16). In the theoretical formula (14), there are several effective terms for the excess energy production such as the terms by Ba, Th, Ni and ${}^1_1$H in addition to that of Pd. Considering these possible contributions to the excess energy, the value given in Eq. (15) will be increased by a factor of one order of magnitude.

4. Conclusion and Discussion

The analysis briefly explained in this paper gives consistent explanation of the experimental data [7] in themselves and also consistent with other experimental data sets obtained since 1989 and explained with our model [1, 2]. Further, specific experiments and more detailed elemental analysis are needed for a conclusive understanding/explanation of the phenomena.

It will be useful to plan novel experiments considering relations of several observables a part of which described in this paper. The science of the cold fusion phenomenon should be established on systematic data sets in physics, chemistry and catalytic chemistry of materials exhibiting wonderful events inexplicable by conventional knowledge.

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