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Research Article

Progress in Energy Generation Research Using Nano-Metal With Hydrogen/Deuterium Gas

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Abstract

The field of condensed matter nuclear science originated in 1989 with Fleischmann and Pons' electrolysis of Pd with heavy water. However, anomalous heat generation and other related phenomena were observed not only by electrochemical methods, but also by loading of deuterium or hydrogen in metals such as Pd and Ni. In this paper, we will first give a short overview of the progress in these gas loading type experiments. After that, we will describe the recent progress of our research team. The authors have been studying energy generation using nano-sized multilayer metal composites with hydrogen gas. Two nano-sized metal multilayer composite samples, which were composed of Ni, Cu, and other thin films on bulk Ni (25 mm $\times$ 25 mm $\times$ 0.1 mm), were used. These samples were fabricated by the Ar ion beam method, or by the magnetron sputtering method. Heat bursts and excess energy generation were observed during the experiments under vacuum conditions ($<10^{-4}$ Pa) using nano-sized metal multilayer composites on Ni substrate and hydrogen gas. Released energy normalized to the total amount of absorbed hydrogen reached 16 keV/H or 1.5 GJ/H-mol. Sometimes spontaneous heat bursts were observed. This suggests that the burst heat release reactions occurred in the near surface region of the nano-sized multilayer metal composite. Furthermore, we have succeeded in intentionally inducing heat bursts, based on the observations of the spontaneous heat bursts. By measuring the optical spectrum emitted from the sample, we detected a simultaneous increase in mid infrared radiation flux when a heat burst occurred.
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Keywords: Excess heat, Anomalous heat, Heat burst, Multilayer thin film, Nano-sized metal composite, Nano material, Hydrogen gas, Gas loading

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1. Introduction

The field of condensed matter nuclear science originated in 1989 with Fleischmann and Pons' electrolysis of Pd with heavy water [1]. However, some researchers started to do different experiments, especially gas loading experiments. Figure 1 shows an overview of the gas loading experiments. De Ninno, Scaramuzzi of ENEA tried to detect neutrons or protons from deuterated Ti [2]. According to the book "Cold Fusion; Advances in Condensed Matter Nuclear Science", Fralick of NASA first did excess heat experiments using Deuterium gas and Pd [3]. Li and Biberian also observed excess heat using Pd and deuterium gas [3]–[4]. Piantelli and Forcadi first did experiments using Ni and Hydrogen [5]. Francesco Celani has been making excess heat experiments with his original method of high voltage pulses to Pd and constantan wires [6]. Brillouin is attempting to commercialize a pulsing method called Q-pulse using Ni and light hydrogen [7].

These studies do not specifically consider the nanoscale. However, the following studies were based on nanoscale materials in addition to gas loading. Arata firstly demonstrated long-term excess heat data using Pd black and Deuterium [8]. Iwamura firstly showed transmutation reactions using deuterium gas with Pd nano-film [9]. Based on these studies, Mizuno, Takahashi, Kitamura, Iwamura and their colleagues made further progress. A Collaborative Research Project between six Japanese organizations funded by NEDO (New Energy and Industrial Technology Development Organization) on anomalous heat effects was done from Oct. 2015 to Oct. 2017 using Ni, Pd, Cu, Zr nanoparticles. Anomalous heat generation, which is too much to be explained by any known chemical process, was observed. Qualitative reproducibility was confirmed between Kobe University and Tohoku University [10]–[11]. The authors replicated the experiments using nano Pd/Ni fabricated by glow discharge with D_2 gas developed by Mizuno [12]. In these experiments, nano-sized particles and diffusion of hydrogen and deuterium were one of the key factors to produce the heat effects.

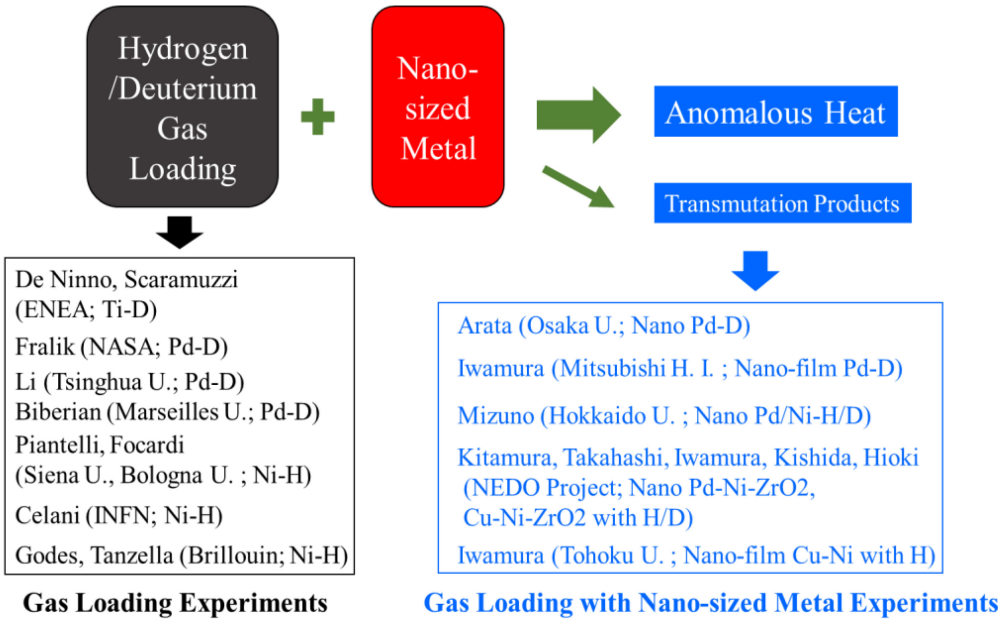


Figure 1. Overview of gas loading experiments and gas loading with nano-sized metal experiments in this field.

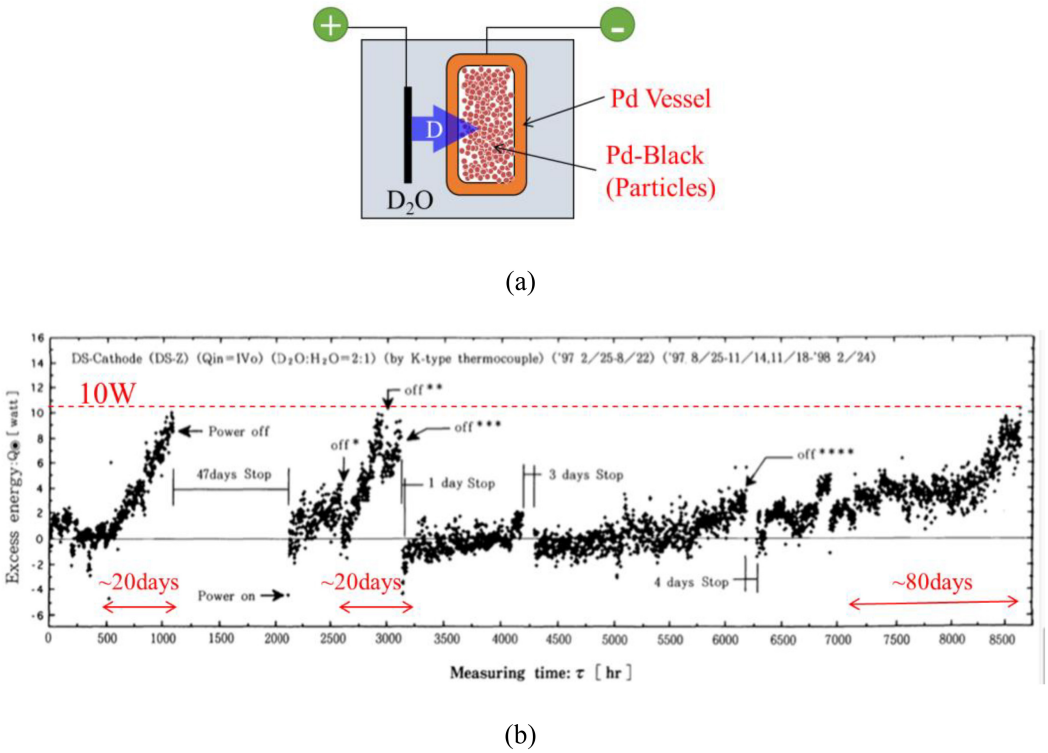


Figure 2. Arata experiment done with gas loading and Pd black particles [8].

Figure 2 shows the first experiment done with gas loading and Pd black particles. In this experiment, as shown in Fig. 2(a), Pd-black particles are packed in a Pd vessel and electrolysis is carried out in heavy water, which results in deuterium gas loading into Pd-black. In this process, heat generation is observed for long durations, as shown in Figure 2(b). This heat generation was evaluated by performing the same experiment with light water electrolysis at the same time, using the light water experiment as a control experiment.

Collaborative research between Technova Inc., Nissan Motor Co. Ltd., Kobe Univ., Kyushu Univ., Nagoya Univ. and Tohoku Univ. was done from Oct. 2015 to Oct. 2017 funded by NEDO (New Energy Development Organization) in Japan. An example of a NEDO experiment with gas loading and metal nanocomposites is shown in Fig. 3. Heat generation experiments using nano-sized metal composite supported by zirconia or by silica with H_2 or D_2 gas were done. Anomalous excess heat generation were observed for all the samples at elevated temperature (150°C-350°C), except for the Pd nanoparticles embedded in mesoporous SiO_2. The amount of anomalous heat generation per hydrogen atom ranged from 10 eV/H or D to 100 eV/H or D, which could not be explained by any known chemical process [10]. Excess heat experiments using the same material at Kobe and Tohoku Universities showed similar experimental results. Coincident burst-like increase events of the pressure of reaction chamber and gas temperature, which suggested sudden energy releases in the reaction chamber, were observed under specific conditions [11].

Next, we describe the recent results of our research team. Initially, one of us (Iwamura) observed transmutation reactions induced by deuterium gas permeation through nanosized Pd multilayers doped with Cs and other elements [9]. In this study, for example, we observed the transmutation of Cs into Pr, which has been reproduced by

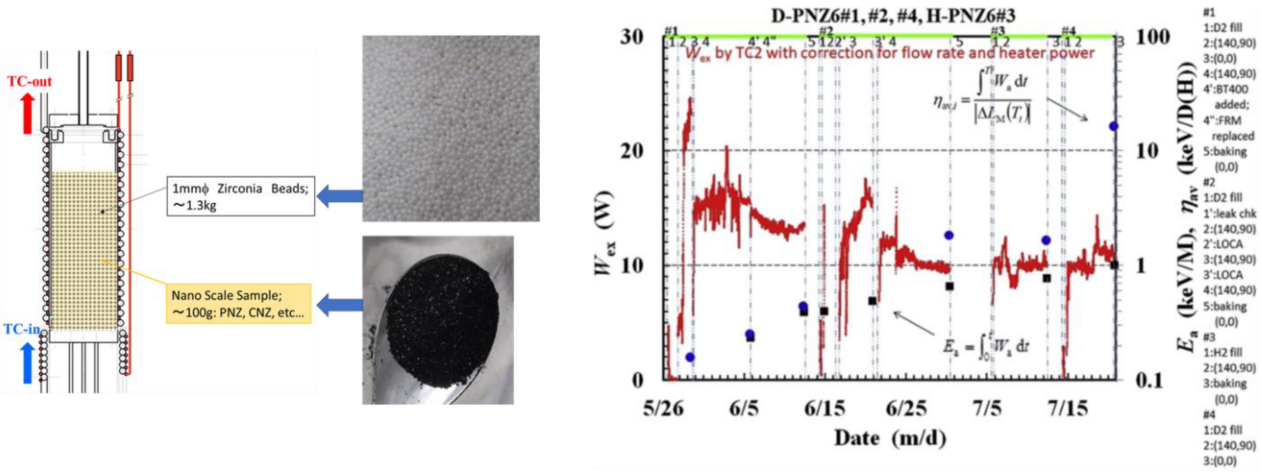


Figure 3. NEDO experiment with gas loading and Metal Nanocomposites [8].

other independent research institutes. This study shows that the diffusion of deuterium and nano-sized multilayers are key factors in inducing the transmutation reaction [9], [12]–[13]. In addition, from the results of the NEDO project mentioned in Fig. 3, we learned that the anomalous phenomena occur not only with deuterium but also with light hydrogen, and that the nano-sized composite particle is one of the key factors to inducing the anomalous phenomena [10]–[11]. By combining the two methods, we have developed a new type of experimental procedure to induce an exothermic reaction by loading light hydrogen in a nickel-based composite material with nano-sized multilayers, and then diffusing the light hydrogen through the nano-multilayers by rapid heating. This new experimental method gave us larger excess energy per H atom [15]–[18].

Recently the author has decided to name the heat generation phenomenon in the system of nano-sized composite metallic materials and hydrogen as QHE (Quantum Hydrogen Energy). The reason for this is that condensed matter nuclear reactions are associated with a complicated and dangerous image that is difficult for the general public to accept.

QHE can be defined as “An exothermic reaction induced by quantum phenomena during the diffusion process in a nanoscale metal composite material with hydrogen”. The characteristics of QHE are as follows: 1) No CO_2 emission and more than 1000 times higher output energy than the combustion reaction of the same amount of hydrogen; 2) QHE does not emit harmful levels of radiation to the human body and has the potential to become a compact, high-power, CO_2-free energy source; 3) QHE could be used as an energy source for the production of electricity and heat.

Figure 6 summarizes the progress from the time of the discovery to the present. The most significant differences between Cold Fusion and QHE are in materials and operating temperatures. In the early stage, expensive materials such as Pd and deuterium were mainly used. However, now we are using nickel and ordinary hydrogen, which is more cost effective. In the beginning, the electrochemical method was mainly used. Electrochemistry is an excellent method for packing deuterium into Pd metal at high density. However, from the perspective of using the excess heat generated for practical purposes, a temperature increase of a few degrees in room temperature heavy water does not have much practical impact, although it was an epoch-making event from a scientific point of view. QHE enables us to obtain heat in the temperature range of several hundred degrees, which makes it possible to use high-temperature gas to turn turbines, which will have an impact on industrialization. Recently, there has been an increasingly strong

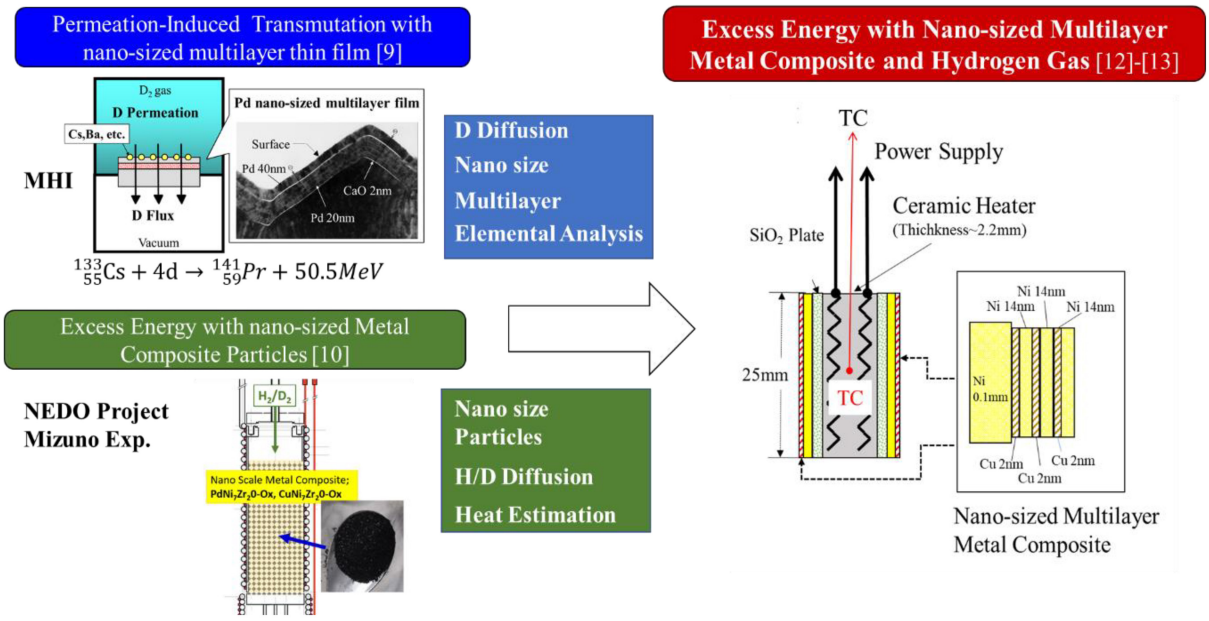


Figure 4. Background and motivation of the present experimental method.

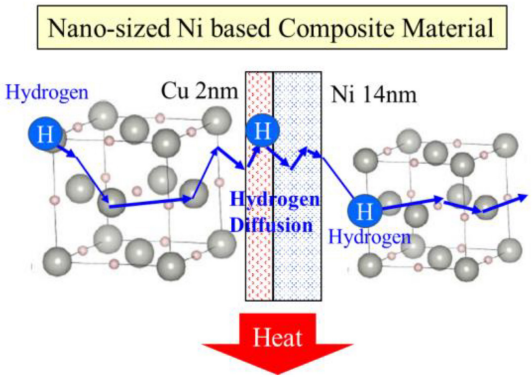
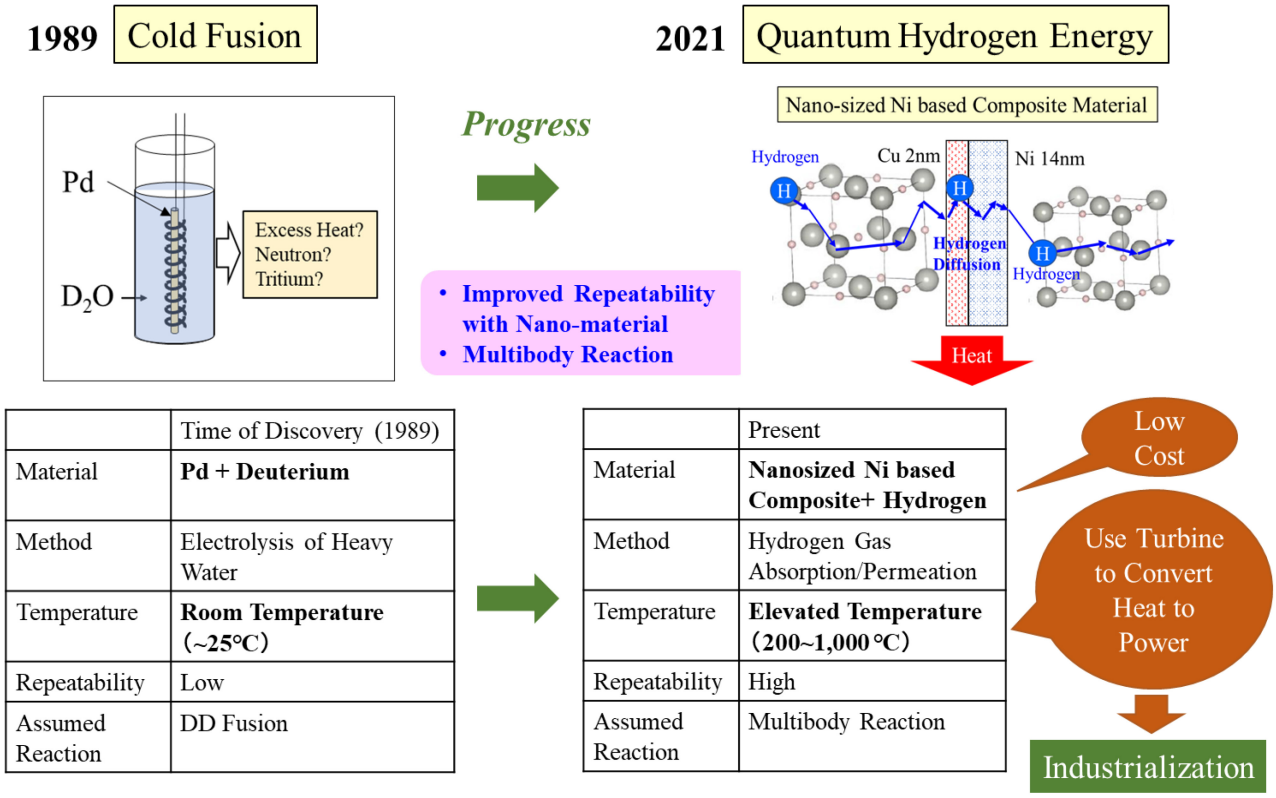


Figure 5. Quantum Hydrogen Energy (QHE).

demand around the world for energy sources that do not emit CO_2 to prevent global warming. QHE using nano-metal and hydrogen could be just the right technology to meet this global social demand.

2. Experimental

A schematic of our experimental apparatus is shown in Fig. 7(a). It is basically the same as in Ref. [17], with improvements in some points [15]–[16]. Two nano-sized metal multilayer composite samples, which were composed of Ni, Cu, CaO thin films on bulk Ni (25 mm × 25 mm × 0.1 mm), placed in the center of the chamber. H_2 gas and its



	Time of Discovery (1989)
Material	**Pd + Deuterium**
Method	Electrolysis of Heavy Water
Temperature	**Room Temperature (~25°C)**
Repeatability	Low
Assumed Reaction	DD Fusion

	Present
Material	**Nanosized Ni based Composite+ Hydrogen**
Method	Hydrogen Gas Absorption/Permeation
Temperature	**Elevated Temperature (200~1,000 °C)**
Repeatability	High
Assumed Reaction	Multibody Reaction

Figure 6. Progress from the time of discovery (1989) to the present.

pressure were monitored by a Pirani gauge. The chamber was evacuated by a turbo molecular pump. The multilayer samples were heated up by a ceramic heater (MS-1000R; Sakaguchi E. H Voc Corp.) in which a thermocouple (TC; Pt-PtRh13%) was embedded.

In the papers [15]–[16], the surface temperature of a sample was measured by an infrared radiation thermometer (IR-CAQ3CS; Chino Corp.). Now, we are able to measure surface temperatures for the two nano-sized metal multilayer composite samples by introducing two thermometer detectors. They were made of InGaAs and dual wavelength mode, 1.55 μm and 1.35 μm, were usually used. During the surface temperature measurement, it was possible to measure the emissivity of the sample surface by switching between single wavelength mode and dual wavelength mode. Heater input power was supplied by a DC power source in constant voltage mode. The input voltage and current were measured both by voltage and current monitors provided by the power supply and an independent voltmeter and amperemeter, respectively. Input power is calibrated using the voltmeter and the amperemeter readings. Gamma-rays and neutrons were monitored by a NaI (Tl) scintillation counter (TCS-1172; Hitachi, Ltd.) and He-3 counter (TPS-1451; Hitachi Ltd.) during all experiments for safety reasons.

A detailed drawing of the Ni based nano-sized metal multilayer composite is shown in Fig. 7(b). It was composed of a Ni Plate (25 mm square and 0.1 mm thick) and Cu-Ni multilayer thin film (20 mm diameter circle and about 100 nm thick). These samples were fabricated by the Ar ion beam method, or the magnetron sputtering method. Two nano-sized metal multilayer composite samples were heated by the ceramic heater (25 mm square and 2.2 mm

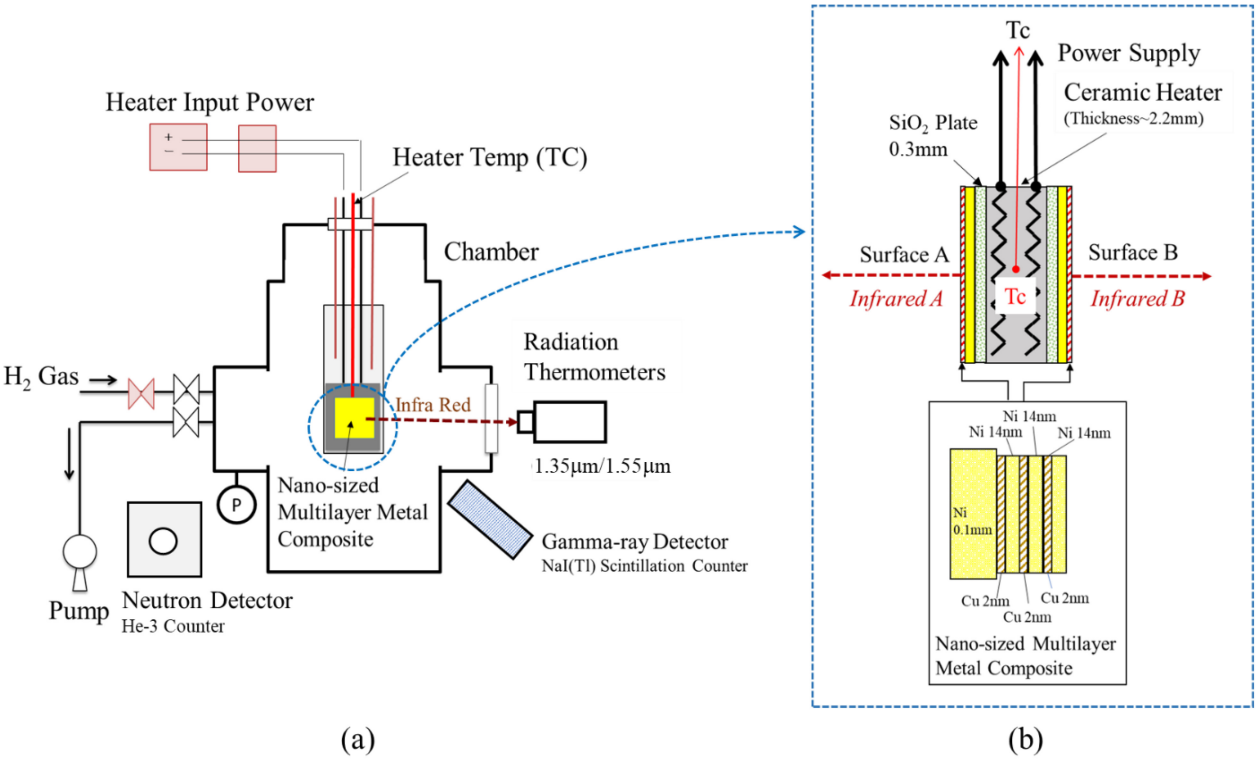


Figure 7. Experimental set-up; (a) Schematic of experimental apparatus, (b) Detail drawing around nano-sized multilayer metal composite.

thick) through SiO_2 plates (0.3 mm thick). If certain energy generation reactions occur on the surface of the samples, the temperature of the embedded thermocouple will rise. Simultaneously, infrared emission detected by the radiation thermometer, which corresponds to the surface temperature of the sample, would increase. Photos of the experimental set-ups and STEM image of Cu-Ni multilayer thin film are shown in Fig. 8.

The experimental procedure is as follows. Two nano-sized metal multilayer composites were placed in the chamber and baked for 2-3 days at heater temperature 900°C to remove H_2O and other hydrocarbons from the surface under vacuum conditions.

According to general knowledge, Cu and Ni diffuse into each other during the baking process, forming a Cu-Ni alloy. However, in our multilayer film, Cu and Ni are not simply alloyed, especially when CaO, Y_2O_3, etc. are added to Ni. The cause of this phenomenon is still under investigation, but it might be due to the effect of oxygen formed on the surface during the sputtering process.

After the baking process, H_2 gas was introduced into the chamber up to about 200 Pa at 250°C. To change the hydrogen loading conditions, the pressure of H_2 gas was sometimes increased up to 30 kPa. H_2 gas was loaded for about 16 hours. Then, H_2 gas was evacuated by the turbo molecular pump and simultaneously the samples were heated up by the ceramic heater up to 500∼900°C. These processes trigger heat generation reactions and anomalous heat. Typically, after 8 hours, the heater input was turned down and the samples were cooled down to 250°C. These processes (H_2 loading, heating up and cooling down samples) were repeated several times, with different heating temperatures or H_2 loading pressure.

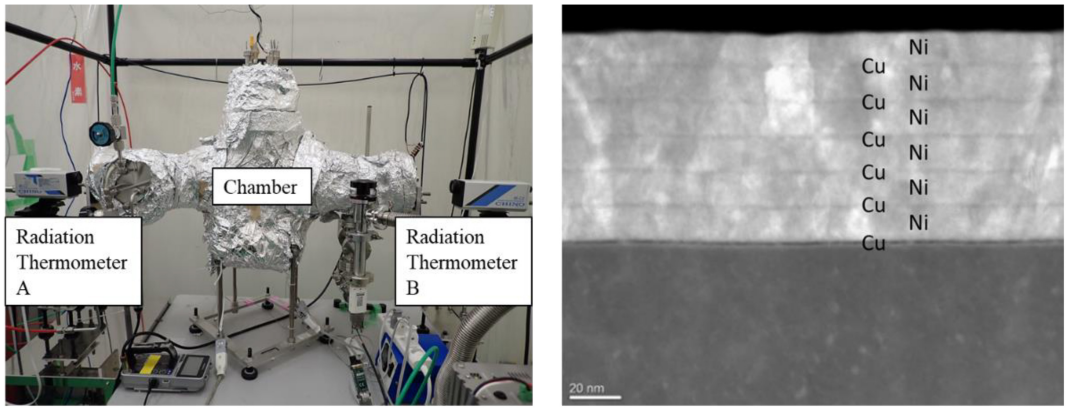


Figure 8. Photos of experimental apparatus and cross-sectional view of nano-sized metal multilayer composites; (a) Outer view of the present experimental Set-ups, (b) STEM (Scanning transmission electron microscope) image of Cu-Ni multilayer thin film.

During the above experimental procedure, hydrogen atoms are assumed to diffuse from the Ni plate through the nano-sized metal multilayer to the surface. The diffusion mechanism of hydrogen atoms is well known as "quantum diffusion" [19]. Hydrogen atoms are hopping from a site to another site in metal. We assume that hydrogen flux is one of the key factors to induce the anomalous heat generation phenomena, and the hydrogen flux is intentionally arranged by the present experimental method. Hydrogen flux $\boldsymbol{J}$ from the nano-sized metal multilayer composite to the chamber is caused by a gradient of hydrogen concentration and gradient of temperature as shown in eq. (1) [20].

$$\boldsymbol{J} = -\mathrm{nD}\left(\nabla \mathrm{c} + \frac{cQ^*\nabla T}{k_B T^2}\right) \tag{1}$$

where n is the number of lattice atoms per unit volume, c is hydrogen concentration defined as the hydrogen/host-metal atom ratio, D is diffusion coefficient and Q* is the heat of transport.

3. Results and Discussion

3.1. Excess Heat Evaluation

Excess Heat is evaluated based on the model described in Fig. 9(a) and the following equation (2).

$$\begin{aligned} k_{eff}\frac{T_C - T_W}{L_{eff}}A_{eff} + A_S\sigma\left\{\varepsilon_A\left(T_{SA}^4 - T_W^4\right) + \varepsilon_B\left(T_{SB}^4 - T_W^4\right)\right\} \\ + A_{Rloss}\varepsilon_{Rloss}\sigma\left(T_{Rloss}^4 - T_W^4\right) = P_{in} + H_{ex}, \end{aligned} \tag{2}$$

where k_{eff} is equivalent thermal conductivity, T_c is the thermocouple temperature embedded in the ceramic heater, T_w is the wall temperature of the chamber, L_{eff} and A_{eff} are effective length and effective surface area between the sample holder and wall, respectively. A_s is the surface area of the sample, T_S is the surface temperature, ε is the emissivity of the sample, σ is the Stefan–Boltzmann constant. subscript A and B means surface A and B, respectively. $A_{Rloss}, \varepsilon_{Rloss}$ and T_{Rloss} are effective surface area; effective emissivity and effective surface temperature for radiation loss except from the sample surface, which is mainly derived from the sample holder. P_{in} is the electrical heater input and H_{ex} is excess power. This equation is obtained under the following assumptions.

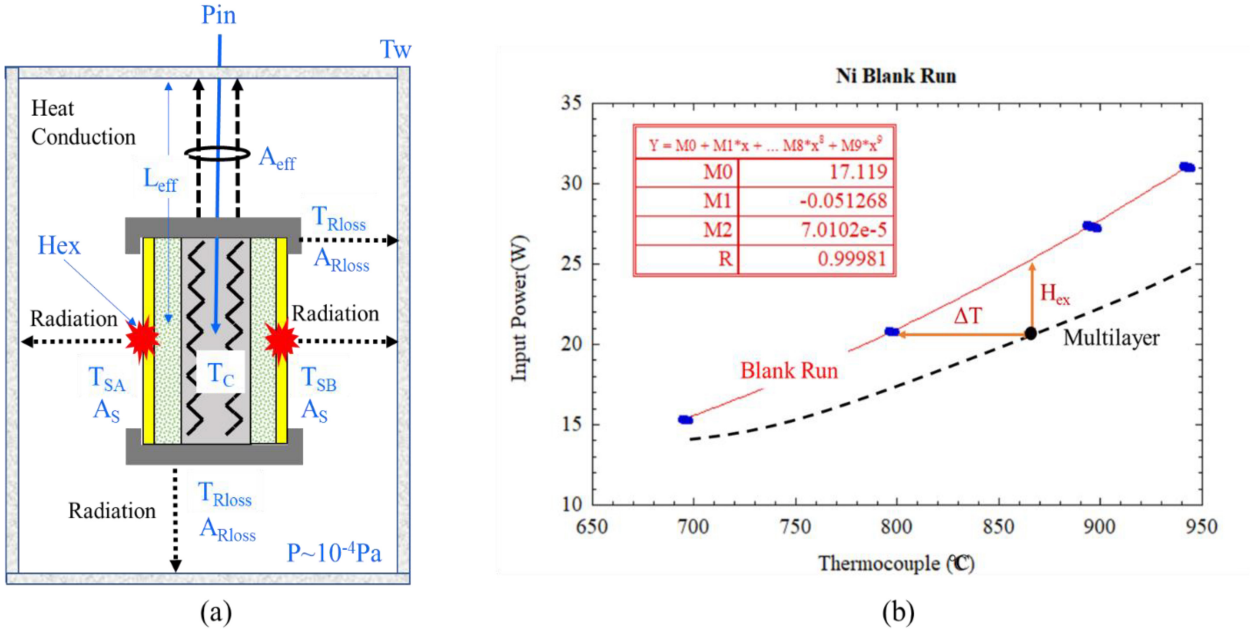


Figure 9. Excess heat evaluation; (a) Model of excess heat evaluation, (b) Relationship between input power (W) and thermocouple temperature (°C) for a blank run and a multilayer run.

1) Thermal conduction via H_2 gas is negligible because H_2 pressure is low.
2) Radiation from the chamber wall is negligible because T_w is room temperature.
3) The electrical input power is constant.

A blank run, in which same sized Ni bulk samples without multilayer thin films were used, was performed with the same procedure described above. Figure 3(b) shows the relationship between input power given to the ceramic heater and heater temperature detected by the thermocouple. As the radiation loss term from the sample holder is the same for Ni bulk and multilayer samples for the same temperature, generated excess heat power is evaluated based on the blank run result as shown in Fig. 3(b). Equation (2) for Ni bulk (subscript "0") is written as:

$$k_{eff}\frac{T_{C0}-T_W}{L_{eff}}A_{eff}+A_S\sigma\left\{\varepsilon_{A0}\left(T_{SA0}^4-T_W^4\right)+\varepsilon_{B0}\left(T_{SB0}^4-T_W^4\right)\right\}$$
$$+A_{Rloss}\varepsilon_{Rloss}\sigma\left(T_{Rloss0}^4-T_W^4\right)=P_{in}. \quad (3)$$

In the papers [15]–[16], excess heat analysis was done based on the assumption that ε is constant for Ni based nano-sized metal multilayer composite and Ni bulk as a first step of data analysis. Emissivity ε can be measured by switching between two wavelengths mode and single wavelength mode. Actual measured emissivity was in the range of 0.1-0.2 at surface temperature 700-750°C, depending on the condition of the sample such as oxidation of surface or surface roughness, the vacuum of the experimental apparatus. However, the difference in emissivity between Ni bulk and Ni multilayer composite samples is within 0.05 (<5%), and the assumed condition is satisfied. Emissivity can be considered almost the same for the Ni bulk and multilayer composite samples.

Excess heat H_{ex} is written based on the equations (2) for multilayer composite and Ni bulk (subscript "0") samples.

$$\begin{aligned} H_{ex} &= k_{eff}\frac{T_C - T_{C0}}{L_{eff}}A_{eff} + A_S\sigma\left\{\varepsilon_A T_{SA}^4 - \varepsilon_{A0}T_{SA0}^4 + \varepsilon_B T_{SB}^4 - \varepsilon_{B0}T_{SB0}^4 - T_W^4\left(\varepsilon_A - \varepsilon_{A0}\right)\right\} \\ &\quad + A_{Rloss}\varepsilon_{Rloss}\sigma\left(T_{Rloss}^4 - T_{Rloss0}^4\right) \\ &\approx k_{eff}\frac{T_C - T_{C0}}{L_{eff}}A_{eff} + A_S\sigma\left\{\varepsilon_A T_{SA}^4 - \varepsilon_{A0}T_{SA0}^4 + \varepsilon_B T_{SB}^4 - \varepsilon_{B0}T_{SB0}^4\right\} + A_{Rloss}\varepsilon_{Rloss}\sigma\left(T_{Rloss}^4 - T_{Ploss0}^4\right) \\ &\because T_{SA,B}^4 \gg T_W^4 \end{aligned} \tag{4}$$

Here, we assume the following relations based on our experimental data. T_{SA} and T_{SB} can be expressed as a linear function of T_c within the experimental parameters.

$$\varepsilon_A \sim \varepsilon_{A0},\ \varepsilon_B \sim \varepsilon_{B0,} T_{SA} \sim \alpha_A T_C + \beta_{A,}\ T_{SB} \sim \alpha_B T_C + \beta_B,\ T_{Rloss} \sim \alpha_{Rloss} T_C + \beta_{Rloss}.$$

ΔT is defined as

$$\Delta T = T_c - T_{c0}. \tag{5}$$

Therefore, the following expression is obtained.

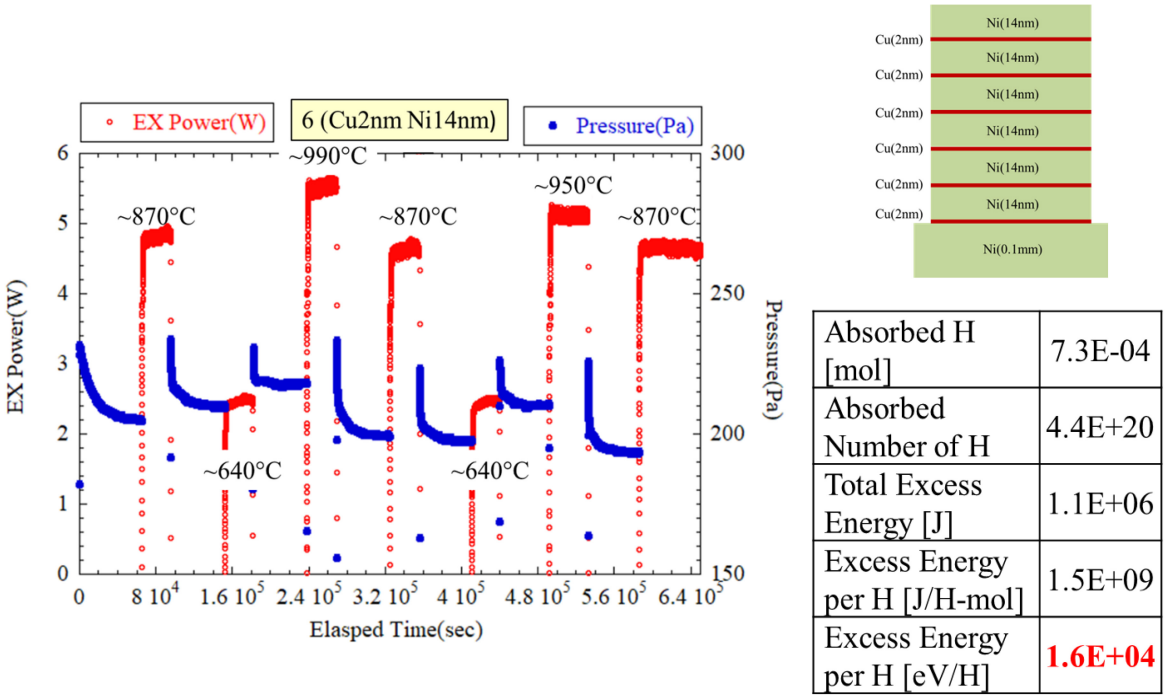
$$\begin{aligned} H_{ex} \approx \Delta T\Bigg\{ &\frac{k_{eff}}{L_{eff}}A_{eff} + A_S\varepsilon_{A0}\sigma\alpha_A\left(T_{SA} + T_{SA0}\right)\left(T_{SA}^2 + T_{SA0}^2\right) \\ &+ A_S\varepsilon_{B0}\sigma\alpha_B\left(T_{SB} + T_{SB0}\right)\left(T_{SB}^2 + T_{SB0}^2\right) + A_{Rloss}\varepsilon_{Rloss}\sigma\left(T_{Rloss} + T_{Rloss0}\right)\left(T_{Rloss}^2 + T_{Rloss0}^2\right)\Bigg\}. \end{aligned} \tag{6}$$

This equation shows that excess heat can be written as a function of ΔT. Therefore, excess heat evaluation by the Ni bulk calibration curve shown in Fig. 3(b) is valid under the assumptions described above.

3.2. Excess Heat Generation

An Example of excess heat generation presented at ICCF22 is shown in Fig. 10 [15]. In this case, the sample which covered 6 CuNi layers (Cu = 2 nm and Ni = 14 nm) were used. Red and blue lines represent excess heat and pressure of the chamber, respectively. At the beginning of the experiment, hydrogen gas was introduced to the chamber and absorbed into the Ni based nano-sized multilayer metal composite at 250°C. The pressure for each experiment gradually decreased as shown in Fig. 10. The amount of hydrogen absorbed by each sample was estimated based on the pressure change and temperature of the chamber. After about 16 hours, H_2 gas was evacuated and simultaneously each sample was heated up by the ceramic heater. After that, excess heat more than input power was observed. The input power was stable during a one cycle; for example, 19 W was applied to the ceramic heater from about 6×10^4 sec to about 1×10^5 sec.

Released excess energy per hydrogen was evaluated based on the experimental result. The amount of absorbed hydrogen, total excess energy and excess energy per absorbed hydrogen are shown in Fig. 10. The amount of excess energy was calculated as 1.1 MJ by time integration of excess power. Although it seems highly unlikely that all the absorbed hydrogen atoms reacted, we can still estimate that average released energies per absorbed total hydrogen was 16 keV/H. Obviously, the released excess energy per hydrogen atom is too large to be explained by any known chemical reactions.



Absorbed H [mol]	7.3E-04
Absorbed Number of H	4.4E+20
Total Excess Energy [J]	1.1E+06
Excess Energy per H [J/H-mol]	1.5E+09
Excess Energy per H [eV/H]	**1.6E+04**

Figure 10. An example of excess heat generation [15].

3.3. Heat Burst Phenomena

In this section, we describe spontaneous heat bursts and intentionally induced heat bursts, which were based on the observations of the spontaneous heat bursts. The research implications of heat bursts are as follows. Usually, in the case of heat measurement as shown in this paper, the heat generation is evaluated using a calibration curve, and there are many cases where people question whether the heat dissipation characteristics are different between the time of calibration and the time of the heat generation experiment due to variations in the way the sample is mounted, etc. We are constantly checking various measurements to see if there are any changes in the heat dissipation characteristics from experiment to experiment. We conclude that the heat burst phenomena cannot be explained by the difference in the heat dissipation characteristics between a calibration and an experiment. The observation of the heat burst phenomena increases the reliability of the heat measurement experiment.

3.3.1. *Spontaneous Heat Burst*

Figure 11 shows temperature time variations for the thermocouple surface A and B. It can be seen that the heat release reaction occurred at the surface A at first and afterwards at the surface B. There, heat bursts propagated to the thermocouple. Input power and room temperature were constant during these events. Therefore, these events were not caused by the change of electrical input power or heat coming in from the environment. The samples consisted of 6 layers of Cu (2 nm) and Ni (14 nm) fabricated by magnetron sputtering on Ni bulk, the same method as in [15]–[16].

The delay time from the burst-like heat release at surface A to the thermocouple is about 33 sec as shown in Fig. 11(a). Delay time from the heat burst at surface B is estimated to be about 40 sec, as an inflection point of T_c can

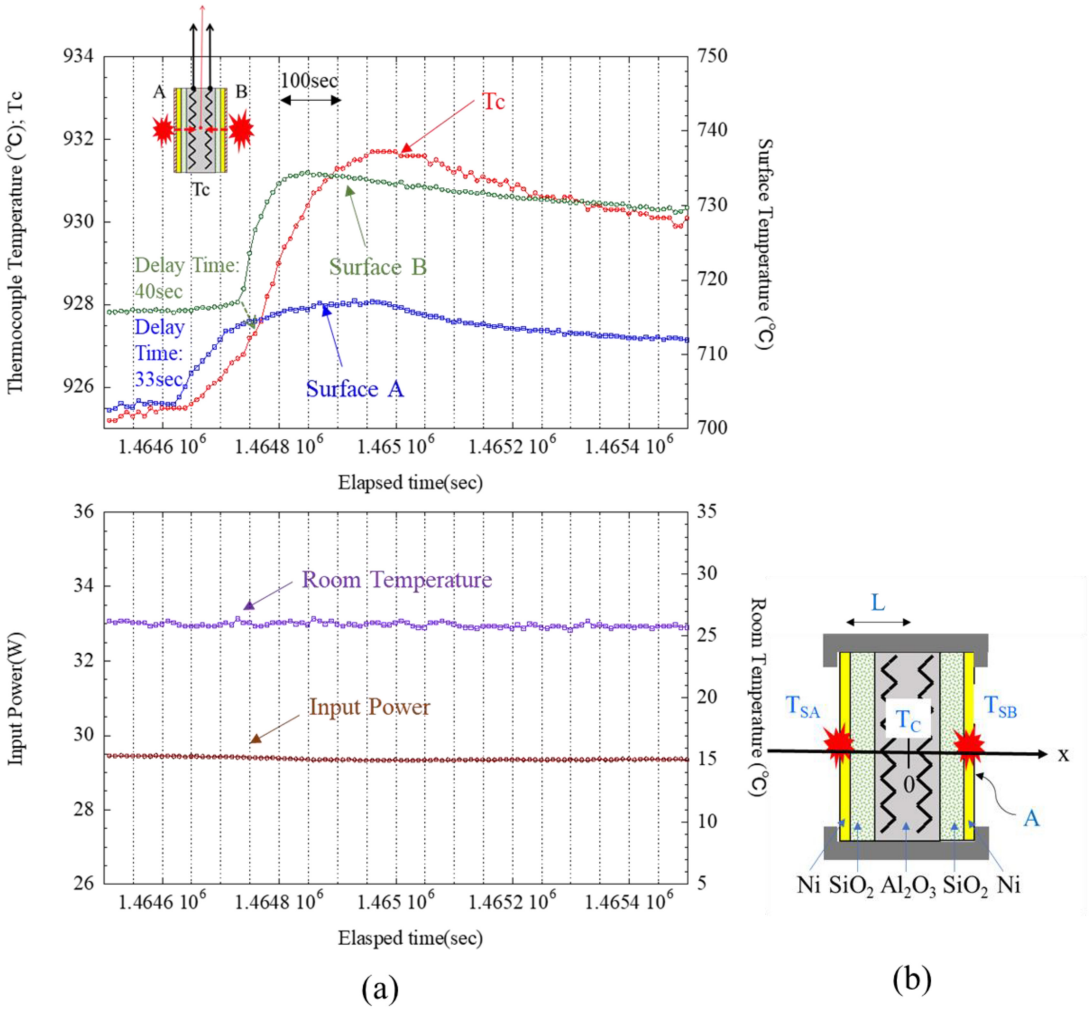


Figure 11. An example of a spontaneous heat burst; (a) Heat burst reactions occurred at the surface A at first and afterwards at the surface B. The heat bursts propagated to the thermocouple. Input power and room temperature were constant during these events, (b) Numerical model for one dimensional non-steady state heat conduction analysis [17].

be seen as shown in Fig. 11(a). Although a 3-dimentional heat analysis would be desirable, a rough estimation of the time constant for the observed burst phenomena can be made.

Figure 11(b) shows the numerical model for one dimensional non-steady state heat conduction analysis. The time constant τ is given as the following equation:

$$\tau = \rho C_p V \frac{L}{k_{Al_2O_3+SiO_2} A} \tag{7}$$

where ρ is the density, C_p is the specific heat, and V is the volume of the sample holder. And k is the thermal conductivity for the mixture of Al_2O_3, SiO_2, A is the surface area and L is the distance between the surface and center of the heater. As Ni is thin and thermal conductivity is larger than Al_2O_3 and SiO_2, the contribution of Ni for

τ is negligible. Based on the rough estimation, τ is calculated as 36 sec. This agrees with the experimental results, therefore the obtained delay times appear to be reasonable. This example gives us clear evidence that burst heat release reactions occurred in the near surface region of the nano-sized multilayer metal composite with hydrogen gas.

3.3.2. *Intentional Heat Burst*

When analyzing the phenomenon of spontaneous sudden heat bursts described above, it was observed that there were cases where the heat burst phenomenon occurred after small changes in input power caused by fluctuations in the outside temperature, etc. Therefore, we conducted an experiment to see what kind of heat burst would occur if we intentionally perturbed the input power. As a result, it became possible to intentionally induce heat burst phenomena depending on (1) the composition and state of the sample, (2) the surface temperature of the sample, and (3) the amount and time range of the input power perturbation.

An example of a heat burst phenomenon induced by an intentional perturbation of input electrical power is shown in Fig. 12(a). At the beginning, 25.8 W was input, and then decreased to 25.0 W. Then the T_C and surface temperature A and B decreased gradually. When the input was returned to the original input of 25.8 W, the surface temperature A, B, and T_c all increased and became larger than the values at the original input of 25.8 W. At maximum, T_c increased by about 9°C, surface A by about 17°C, and surface B by about 25°C. The increases in surface A and B temperatures were larger and steeper than that of T_c as shown in Fig. 12(a). It can be considered that heat burst energy generated at the surface A and B, which is induced by the intentional perturbation of input power, propagated to the thermocouple.

On the other hand, an example of no heat burst phenomenon induced by a similar perturbation is shown in Fig. 12(b). In this case, when the input power, which was initially 26.3 W, was reduced to 25.8 W, the thermocouple and surface temperatures A and B gradually decreased as in Fig. 12(a). Then, when the input power was returned to 26.3 W, the heat burst phenomenon did not occur, and the thermocouple and surface temperatures A and B returned to their original values.

The same experimental setup was used for these two examples, but the compositions of the samples were different. Figure 12(a) is a 6-layer CuNi sample, and Figure 12(b) is a 6-layer CuNi sample with CaO inserted into the Ni layer. The conditions under which this phenomenon occurs are being investigated in detail.

The experimental results related to this phenomenon were observed by the Focardi team [5]. They used Ni rods and hydrogen. They observed excess heat by once bringing the temperature of the Ni rods down to near room temperature and then abruptly returning it to the original input power level. Although the experimental methods are different, the same physicochemical mechanism related to the diffusion of hydrogen seems to be behind the experimental results.

3.3.3. *Observation of Heat Burst Phenomena by Thermocouple and Mid-IR*

In order to elucidate the mechanism of the anomalous heat phenomena, our research team has been conducting experiments using the same type of sample holder described in 3.3.1 and 3.3.2 to measure the light spectrum emitted from the sample surface during the generation of anomalous heat [18]. Here, we introduce the recently observed results [21].

Figure 13 shows the time variation between the integrated spectrum of infrared light in the mid-IR region (0.23-0.41 eV) and the thermocouple temperature (T_c) embedded in the center of the heater when multiple spontaneous heat bursts occurred. As shown in the figure, the mid-IR data is the infrared radiation emitted from surface A. In addition to this mid-IR, visible light emitted from surface B and near-IR (0.5-0.75 eV) were also measured in this experiment, but they are not shown here for simplicity. Many sudden spontaneous increases are clearly seen, even though the heater input power is constant. T_c and mid-IR (0.23-0.41 eV) seem to be synchronized. This suggests that there was sudden energy generation near the surface of the nano-sized multilayer composite, part of it was dissipated quickly by radiation from the surface and was partly propagated to the inside, raising the heater temperature in the same way

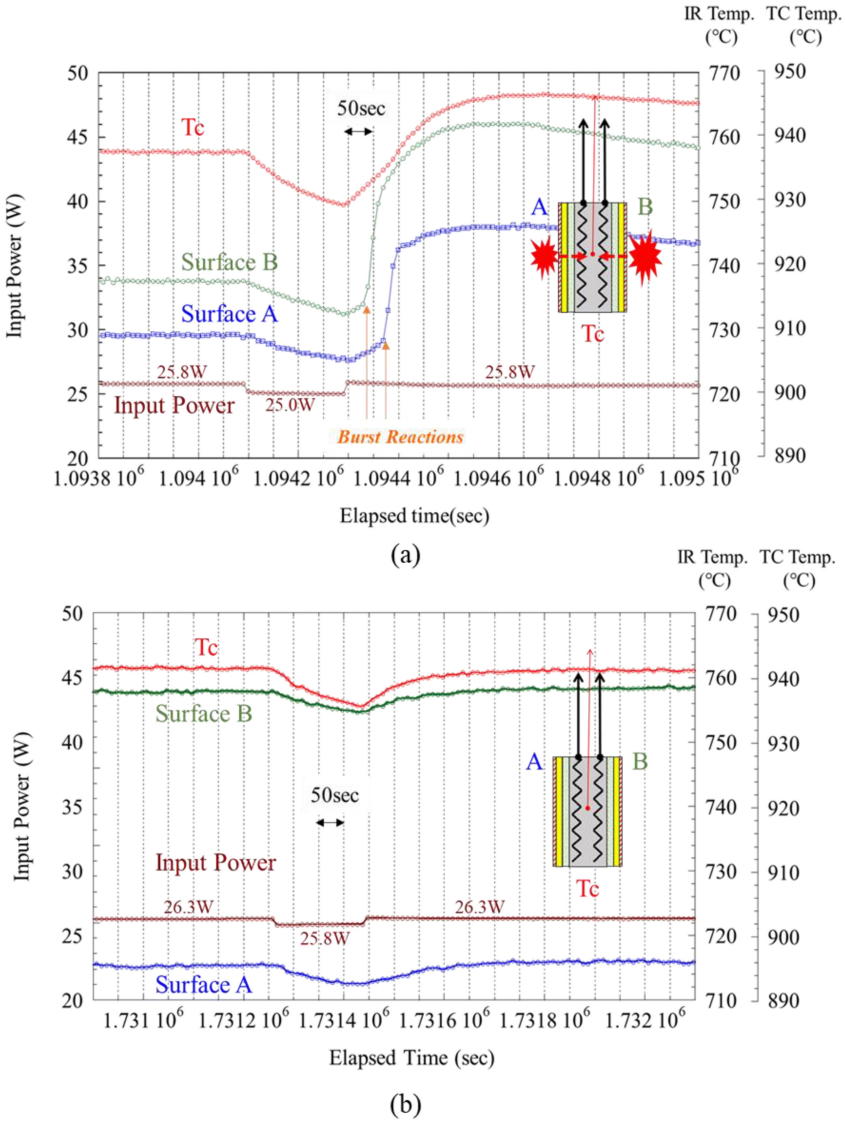


Figure 12. Different responses to intentional perturbations of input power: (a) An example of heat burst phenomenon induced by an intentional perturbation of input electrical power, (b) An example where no heat burst phenomenon was induced by a similar perturbation.

described in Fig. 11 and 12. The radiation thermometers used in Figs. 11 and 12 calculated the surface temperature from the infrared intensity at two wavelengths, 1.55 μm (0.80 eV) and 1.35 μm (0.92 eV). In other words, the surface temperature was calculated from the infrared intensities at 0.80 eV and 0.92 eV, and the heat burst was observed almost synchronously with T_c. It is important to note that not only 0.80 eV and 0.92 eV, but also 0.23-0.41 eV infrared, which is lower in energy and longer in wavelength, correlated with T_c.

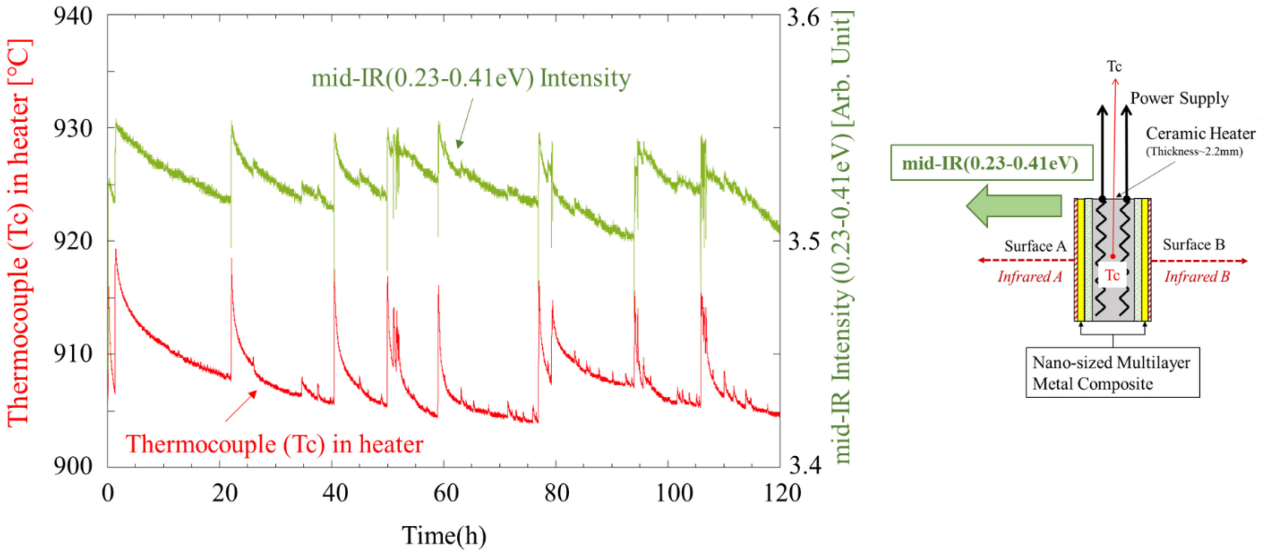


Figure 13. Observation of heat burst phenomena by thermocouple and mid-IR.

4. Future Scientific and Technological Challenges

Here, we briefly describe the future challenges for QHE. First of all, it is now known that the use of nano-sized multilayer composite metals and hydrogen can generate abnormal heat, which is several thousand times higher than the chemical reaction per unit of hydrogen fuel, but the mechanism of the phenomenon is still unknown. Therefore, the most important task is to identify the reaction responsible for this anomalous heat generation. It is also necessary to identify the reaction products, and to show that the heat generation and the products are consistent. This will require a very clean experimental environment and a synchrotron radiation facility such as SPring-8 for trace element analysis. It is also important to develop a theoretical model to explain the reaction.

Let us consider the development of an energy generator by QHE. There are many theoretical difficulties, but there are fewer inherently difficult engineering challenges in temperature range, materials, and fuels than tokamak plasma fusion. Therefore, in parallel with the theoretical clarification, it is urgent to develop a demonstration device that can convince people that it can be used as an energy source. At the same time, public acceptance is an extremely important issue for QHE, which should be solved in the future.

5. Concluding Remarks

Anomalous heat using nano-metal with hydrogen/deuterium gas could become a technology to prevent global warming, if it can be commercialized. An overview of the progress of gas loading type experiments, in which deuterium or hydrogen and metals such as Pd and Ni were utilized, was described. Among them, nano-sized Ni based composite material began to attract attention from industry because of its abundance on earth, lower cost, and its ability to react with hydrogen at several hundred degrees centigrade. Our team developed a new type of energy generation method using a nano-sized metal multilayer composite and hydrogen gas. We have now started to call the generated energy “Quantum Hydrogen Energy (QHE)”. According to our experimental results, Exothermic reactions that cannot be explained by chemical reactions were observed in Cu/Ni and Cu/Ni multilayer metal composites. The amount of

heat generation reached to 16 keV/H. Not only steady-state heat generation, but also heat burst phenomena were observed. Experimental data analysis showed that the exothermic reaction occurred near the surface. Recently, we have succeeded in intentionally inducing heat bursts. By measuring the optical spectrum emitted from the sample, we detected a simultaneous increase in mid infrared radiation flux when a heat burst occurred. This emerging technology is expected to be commercially feasible.

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