Energy Generation using Nano-sized Multilayer Metal Composites with Hydrogen Gas; Intentional Induction of Heat Burst Phenomenon

Yasuhiro Iwamura[1], Takehiko Itoh[1,2], Tomonori Takahashi[2], Shinobu Yamauchi[2], Mari Saito[2], S. Murakami[2] and Jirohta Kasagi[1]

[1]Research Center for Electron Photon Science, Tohoku University, Sendai, 982-0826, Japan
[2]CLEAN PLANET Inc., Tokyo, 105-0022, Japan

E-mail: iwamura@lns.tohoku.ac.jp

Abstract

An innovative heat generation method using Ni based nano-sized metal multilayer thin films with hydrogen has been investigating by our team. Anomalously large heat generation up to about 20keV/H, which was too high to be explained by known chemical reactions, was induced by heating up the metal multilayer thin film that absorbed hydrogen gas in advance.

Spontaneous heat burst phenomena during excess energy generation has been observed, which was reported at JCF21. In this study, we reported that we succeeded in intentionally inducing such a heat burst phenomenon. For example, a heater input of 25.8 W could be reduced to 25.0 W and then returned to the original 25.8 W after 3 minutes to cause a heat burst phenomenon in which the surface temperature rises 20°C to 30°C for several minutes. Considering that the pressure in the chamber is less than 10^{-4} Pa, the energy released in this heat burst cannot be explained by any known chemical reactions such as hydrogen combustion. This phenomenon has been observed frequently, although it depends on the state of sample. At present, we assume that the temperature distribution change due to the perturbation in input power and hydrogen diffusion and concentration are involved in intentional induction of heat burst phenomenon.

1. Introduction

Our research team has been studying innovative methods of generating heat using Ni-based nano-sized multilayer metal [1]-[5]. This experimental method was developed based on the experiments on permeation- induced transmutation using deuterium and palladium multilayers [6]-[9] and on anomalous heat generation using nanoparticles [10]-[13].

The permeation-induced transmutation phenomenon, which is completely different from conventional transmutation by nuclear reactors or accelerators. D_2 gas permeation through a nano-structured multilayer thin film composed of Pd and CaO thin film and Pd substrate with a target element induces nuclear transmutation reactions [6]-[9]. It was firstly observed at Mitsubishi Heavy Industries [6] and successfully replicated by other institutes such as Toyota R&D center [14]. Typical target element is Cs and produced element is Pr. Transmutation reactions of Sr, Ba, W into Mo, Sm, Pt were also observed by this method. In this research, deuterium diffusion through nano-sized multilayer thin film was a key factor and the elemental analysis was key technique.

NEDO (New Energy and Industrial Technology Development Organization) research project on anomalous heat effects using Ni, Pd, Cu, Zr nano particles was done from Oct.

2015 to Oct. 2017 [10]-[13]. Anomalous heat generation, which is too much to be explained by any known chemical process, was observed. Qualitative reproducibility was confirmed between the Kobe University and Tohoku University. In the paper [13], coincident burst events of the reaction chamber pressure and gas temperature were observed many times using Cu, Ni and Zr nanoparticles with H_2 gas. It suggested heat burst energy releases in the reaction chamber. In these experiments, nano-sized particles and diffusion of hydrogen and deuterium were one of key factors to observe the heat effects and precise heat estimation was crucial.

Combining above important factors and methods to induce transmutation and heat generation reactions, we developed a present method using a nano-sized metal multilayer composite and hydrogen gas. During the anomalous heat experiments, we discovered that spontaneous heat bursts occur during excess heat generation. Even the energy generated by a single heat burst was too large to be explained by the chemical reactions of the materials in the vacuum chamber. By precisely analyzing the experimental conditions under which this spontaneous heat burst phenomenon occurred, we attempted to intentionally cause heat generation bursts. This paper focuses on heat burst phenomena and discusses the fact that even a single heat burst phenomenon cannot be explained by known chemical reactions and the significance of observing heat burst phenomena in heat measurement.

2. Experimental

Experimental method is basically the same with the paper [1]. Experimental set-up is shown in Fig.1. 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 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 in which a thermocouple (TC; Pt-PtRh13%) was embedded.

In the papers [1]-[2], the surface temperature of a sample was measured by an infrared radiation thermometer (IR-CAQ3CS; Chino Corp.). Now, we can measure surface temperatures for the two nano-sized metal multilayer composite samples by introducing two thermometer detectors. They were made of In GaAs 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.

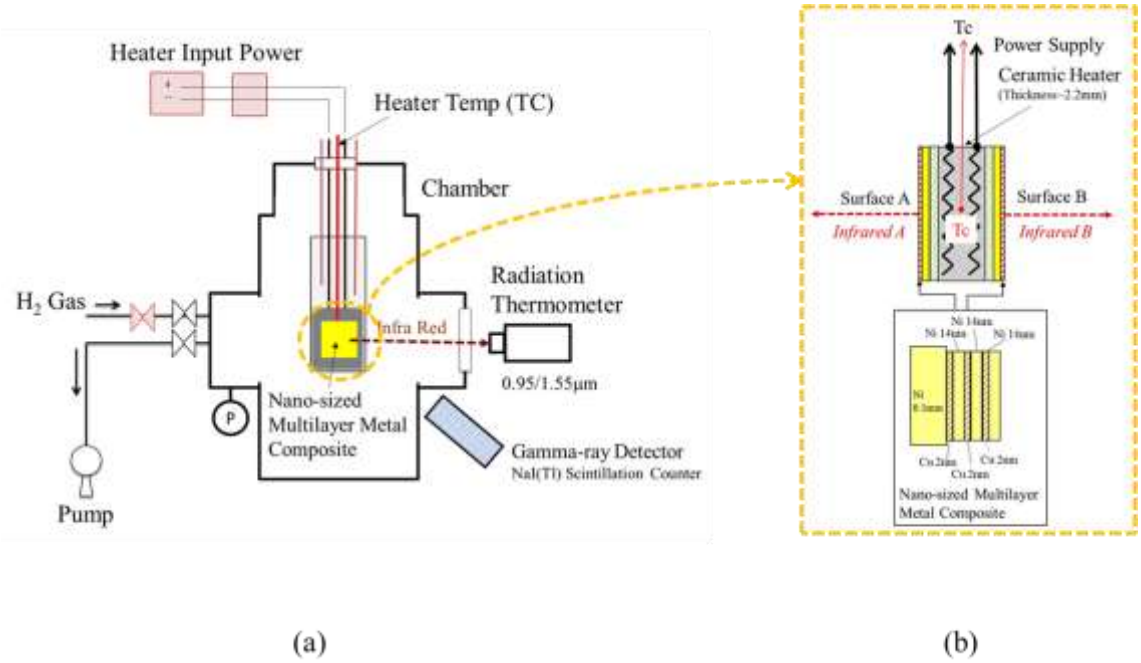

Figure 1. Experimental set-up; (a) schematic of experimental apparatus, (b) detail drawing around nano-sized multilayer metal composite [1].

A detailed drawing of the Ni based nano-sized metal multilayer composite is shown in Fig. 1(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 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. 2.

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.

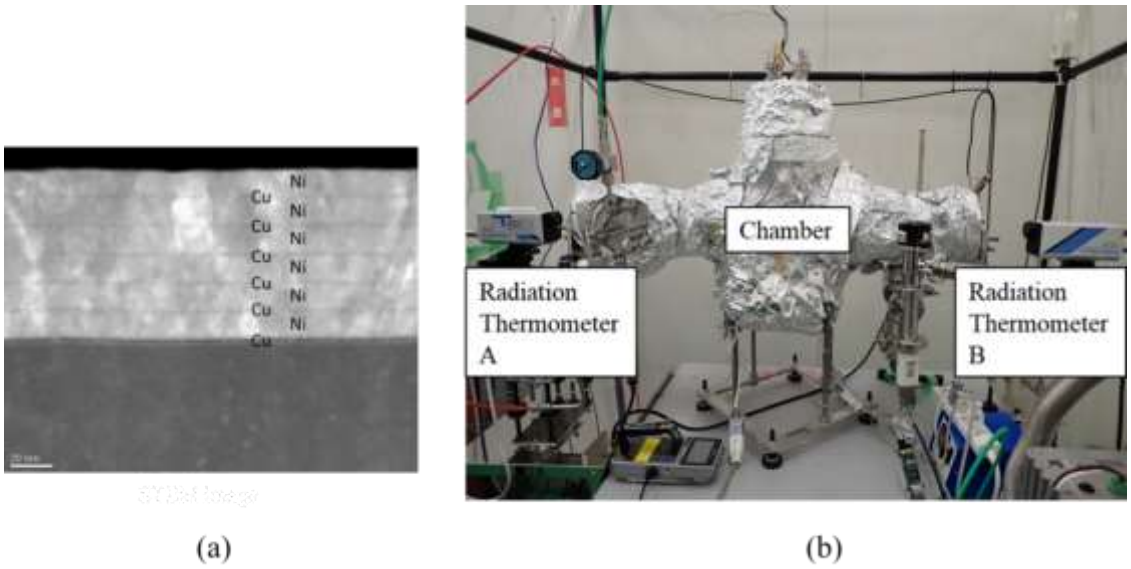

Figure 2. Photos of experimental apparatus and cross-sectional view of nano-sized metal multilayer composites; (a) STEM (Scanning transmission electron microscope) image of Cu-Ni multilayer thin film, (b) outer view of the present experimental set-ups.

During the above experimental procedure, hydrogen atoms are supposed 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" at low temperature [15]. 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 condensed matter nuclear reactions and the hydrogen flux is intentionally arranged by the present experimental method. Hydrogen flux J from the nano-sized metal multilayer composite to the chamber is caused by gradient of hydrogen concentration and gradient of temperature as shown in eq. (1)[16].

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

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.3(a) and the following equation (2).

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

where k_{eff} is equivalent thermal conductivity, Tc is the thermocouple temperature embedded in the ceramic heater, Tw is wall temperature of the chamber, L_{eff} and A_{eff} are effective length and effective surface area between the sample holder and wall, respectively. As is 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. $A_{Rloss,}$ ε_{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.

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

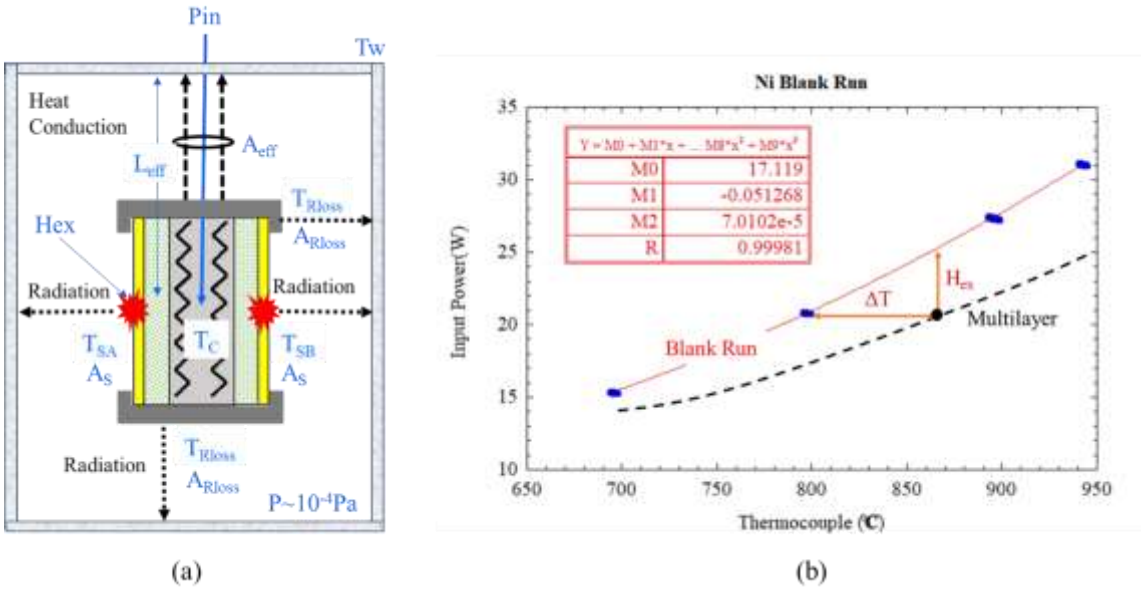

Figure 3. Method for excess heat evaluation; (a) model of excess heat evaluation, (b) relationship between input power(W) and thermocouple temperature (TC) for a blank run and a multilayer run.

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 supposed to be evaluated based on the blank run result as shown in Fig.3(b). Equation (2) for Ni bulk (subscript "0") is written as

$$k_{eff}\frac{T_{C0}-T_W}{L_{eff}}A_{eff}+A_S\sigma\{\varepsilon_{A0}(T_{SA0}^4-T_W^4)+\varepsilon_{B0}(T_{SB0}^4-T_W^4)\}$$

$$+\ A_{Rloss}\varepsilon_{Rloss}\sigma(T_{Rloss0}^4-T_W^4)=P_{in}. \quad (3)$$

In the papers [2]-[5], excess heat analysis was executed 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 two wavelengths mode and single wavelength mode. Actual measured emissivity was in the range of 0.1-0.2 at surface temperature 700-750 ℃, 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. It would be possible to consider that emissivity was almost the same for the Ni bulk and multilayer composite samples.

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

$$H_{ex}=k_{eff}\frac{T_C-T_{C0}}{L_{eff}}A_{eff}+A_S\sigma\{\varepsilon_AT_{SA}^4-\varepsilon_{A0}T_{SA0}^4+\varepsilon_BT_{SB}^4-\varepsilon_{B0}T_{SB0}^4-T_W^4(\varepsilon_A-\varepsilon_{A0})\ \}+A_{Rloss}\varepsilon_{Rloss}\sigma(T_{Rloss}^4-T_{Rloss0}^4)$$

$$\approx k_{eff}\frac{T_C-T_{C0}}{L_{eff}}A_{eff}+A_S\sigma\{\varepsilon_AT_{SA}^4-\varepsilon_{A0}T_{SA0}^4+\varepsilon_BT_{SB}^4-\varepsilon_{B0}T_{SB0}^4\ \}+A_{Rloss}\varepsilon_{Rloss}\sigma(T_{Rloss}^4-T_{Ploss0}^4) \quad \because\ T_{SA,B}^4\gg T_W^4 \quad (4)$$

Now, we assume the following relations based on our experimental data. It is possible that T_{SA} and T_{SB} can be expressed as liner function of Tc within the experimental parameters.

$$\varepsilon_A\approx\varepsilon_{A0},\ \varepsilon_B\approx\varepsilon_{B0},\ T_{SA}\approx\alpha_AT_C+\beta_A,\ T_{SB}\approx\alpha_BT_C+\beta_B,\ T_{Rloss}\approx\alpha_{Rloss}T_C+\beta_{Rloss}.$$

ΔT is defined as

$$\Delta T=T_c-T_{c0}. \quad (5)$$

Therefore, the following expression is obtained.

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

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 Experimental Results

Before describing heat burst phenomena, a typical example of anomalous heat generation, already published [2], is shown in Fig.3. Red and blue lines mean 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℃. The pressure for each experiment gradually decreased as shown in the Fig. 3. The amount of hydrogen absorbed by the sample could be estimated based on the pressure change and temperature of the chamber.

After about 6×10^4 sec, H_2 gas was evacuated and simultaneously each sample was heated up rapidly by the ceramic heater. After that, excess heat generation more than input power was triggered by the rapid heating and hydrogen diffusion. Excess heat is calculated using the previously described method. For example, the first excess heat is about 5W at a heater temperature of about 870°C for an input of 19W. 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 9×10^4 sec.

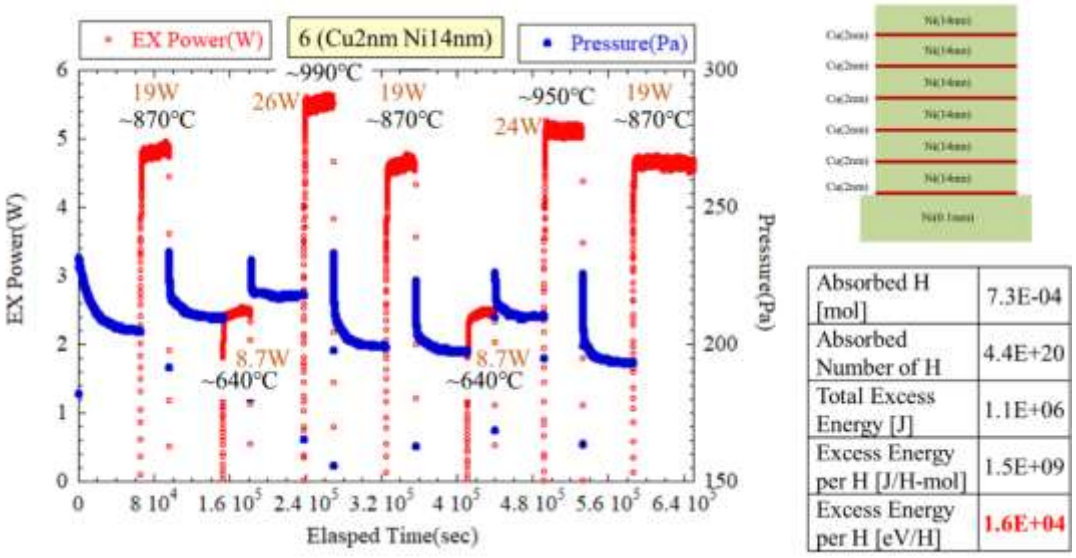

Figure 4. Example of anomalous heat generation [2].

From the decrease in pressure in the vacuum chamber, the total amount of hydrogen absorbed in this sample can be calculated as 7.3×10^{-4}mol or 4.4×10^{20} as shown on the right side of the Fig.4. By integrating this excess heat with time, the total energy released in this experiment can be calculated as 1.1 MJ. It is difficult to assume that all of the absorbed hydrogen is involved in the excess heat generation, and much of it is simply

released from the sample due to heating, but here we divide the total energy by the amount of hydrogen absorbed to avoid overestimation. This yields a value of 16 keV/H or 1.5 GJ/H-mol.

In normal chemical reactions, the amount of energy generated per hydrogen is on the order of eV. This is because chemical reactions can only release energy at the level of electron binding energy. Compared to this, the value of 16 keV/H just obtained is an order of magnitude higher, even though it is an underestimate. Released energy per hydrogen cannot be explained by any known chemical process and suggests that the observed heat generation might be of nuclear origin.

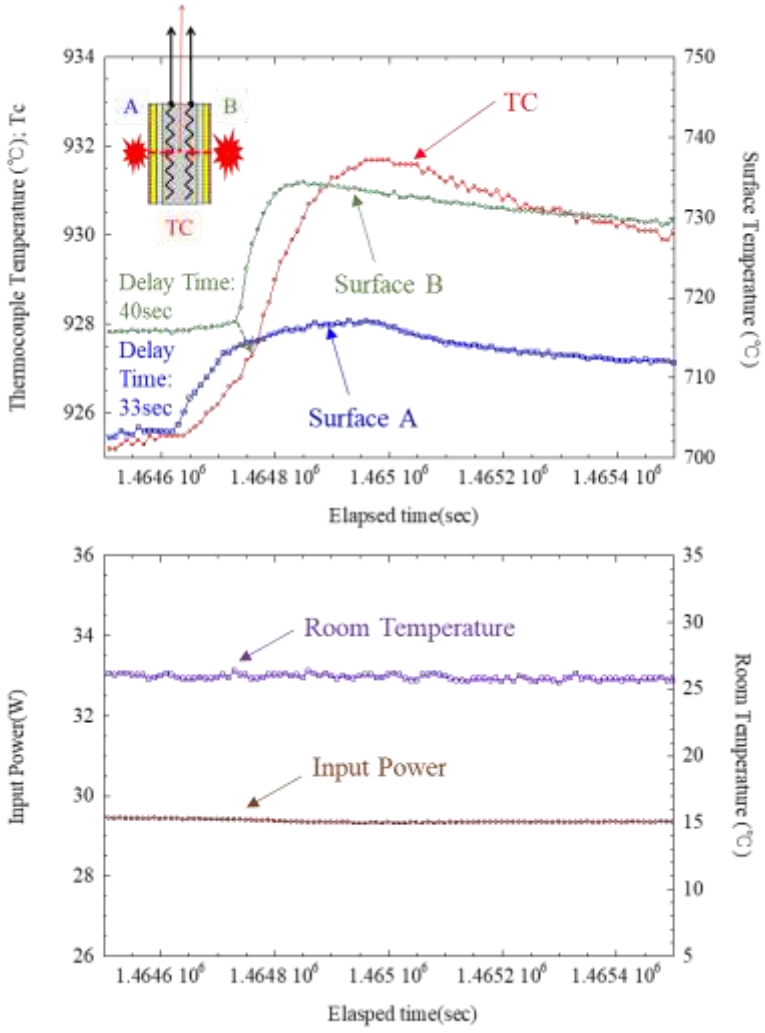

Figure 5. An example of spontaneous heat burst, which occurred at the surface A at first and afterwards at the surface B. Their heat bursts induced the rise of Tc. Input power and room temperature were constant during these events [1].

Next, an example of a spontaneous thermal burst is described. As shown in Fig. 5, a heat burst occurred suddenly on surface A, and the heat propagated to the thermocouple (TC) at the center of the ceramic heater, followed by a heat burst on surface

B, which further propagated to the TC. Input power and room temperature were constant during these events. Therefore, the heat burst 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.

Delay time from the spontaneous heat burst at surface A and B to the thermocouple was about 33 and 40 sec, respectively. Based on the specific heat and size data for the sample, ceramic heater and sample holder materials (Al_2O_3 and SiO_2), the time constant when heat is generated on the sample surface can be calculated to be approximately 36 seconds (see [1]). Therefore, the delay time obtained from the experiment is almost the same, and it is consistent to assume that the heat burst occurred near the sample surface. This example gives us clear evidence that heat release reactions occurred in the near surface region of the nano-sized multilayer metal composite with hydrogen gas.

When analyzing the phenomenon of spontaneous sudden heat bursts described above, it was observed that there were some cases where the heat burst phenomenon occurred after small deviations in input power caused by fluctuations in the outside temperature, etc. Therefore, we tried to reproduce the heat burst phenomena by perturbating the electrical input power. As a result, it became possible to intentionally induce heat burst phenomena.

An example of a heat burst phenomenon induced by an intentional perturbation of input electrical power is shown in Fig. 6 (a). At the beginning, 25.8 W was input, and then decreased to 25.0 W. Then the TC 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 Tc all increased and became larger than the values at the original input of 25.8 W. At maximum, Tc 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 Tc as shown in Fig. 6 (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. 6 (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. 6(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 6 (a) is a 6-layer $CuNi_7$ sample, and Figure 6 (b) is a 6-layer $CuNi_7$ sample with CaO inserted into the Ni layer. The conditions under which this phenomenon occurs are being investigated in detail. According to experimental results, it depends 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. At present, we assume that the temperature distribution change due to the perturbation in input power and hydrogen diffusion and concentration are involved in intentional induction of heat burst phenomenon.

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.

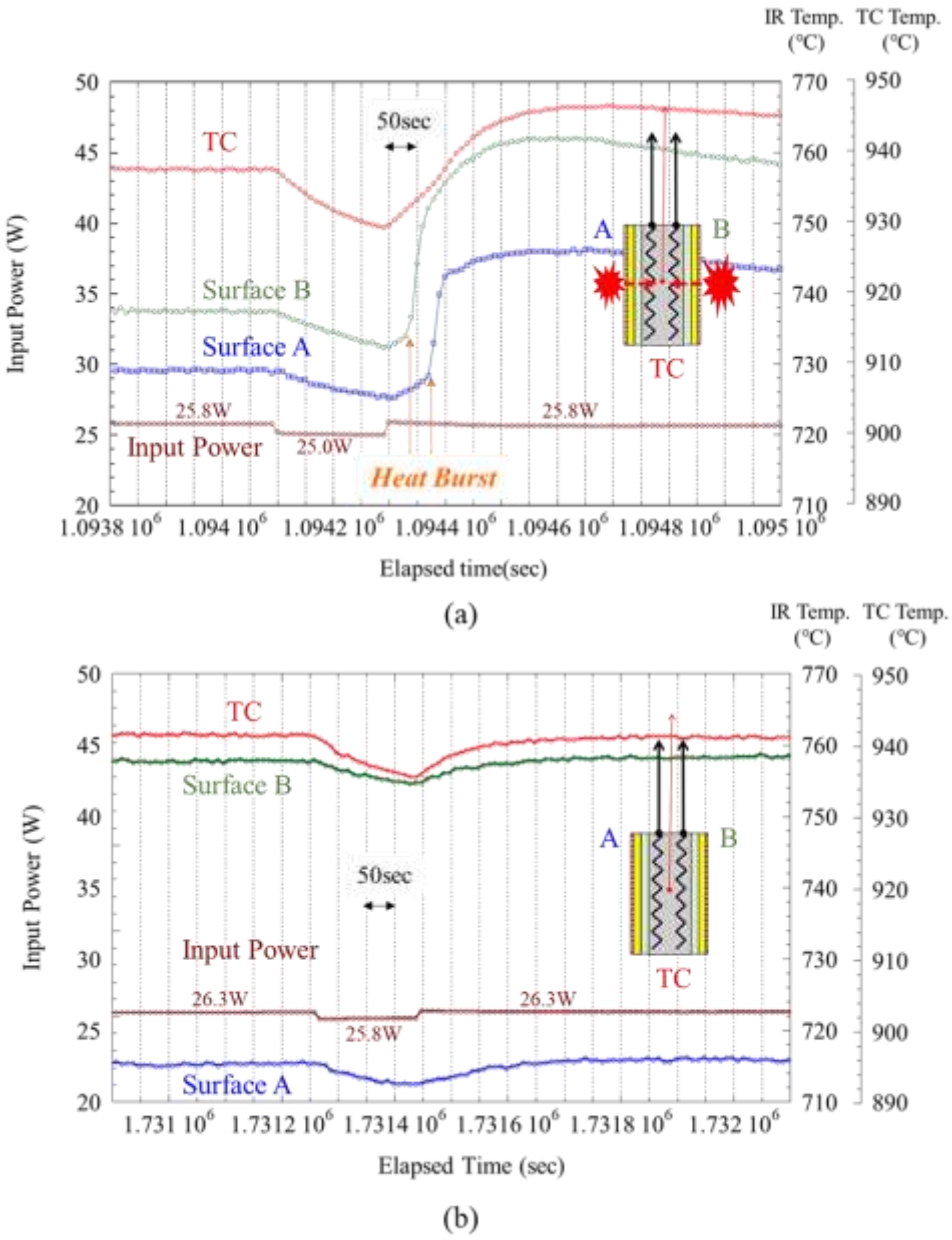

Figure 6. Intentional heat burst induced by a perturbation in input power: (a) an example of heat burst phenomena induced by the intentional perturbation in input electrical power, (b) an example of no heat burst phenomena.

Next, we examine the possibility that the observed heat burst phenomenon was caused by some chemical reactions. Figure 7 plots the change in excess power during the intentionally induced heat burst shown in Fig. 6. At about 1.0944×10^5 sec, a heat burst induced by the perturbation of input power. About 5.5 W excess heat was obtained before the input power perturbation and it increased up to 6.5 W after the perturbation in input power and gradually decreased. The excess increase due to the heat burst lasted for at least 1.2×10^4 seconds. 12 kJ energy release by the one heat burst can be calculated by integrating excess power with time.

Whether the energy obtained from this single heat burst can be explained by chemical reactions is discussed below. During the heat release experimental cycle, all the hydrogen introduced for absorption was evacuated, and the degree of vacuum was less than 1×10^{-4} Pa when the heat burst phenomenon was observed. Therefore, the number of moles of residual gas was less than 4×10^{-10} mol. Chemical reactions that could generate heat under these circumstances are as follows.

(1) When the residual gas in the chamber is all oxygen and the absorbed hydrogen is oxidized and generates heat.

(2) When the residual gas is oxygen and Ni metal is oxidized.

(3) When the residual gas is a mixture (H_2:O_2=2:1) and its combustion energy energizes the surfaces of the two samples.

It is known that the combustion reaction of hydrogen is about 290 kJ/mol and the heat of formation of nickel oxide is about 240 kJ/mol. Since the number of moles of residual gas in the chamber was less than 4×10^{-10} mol, the heat generated in each case can be calculated less than 10^{-3} J. It is completely negligible if we compare the energy increased by the heat burst: 12kJ. This clearly shows that at least the chemical reactions (1)-(3) cannot explain the heat burst phenomenon observed in this study.

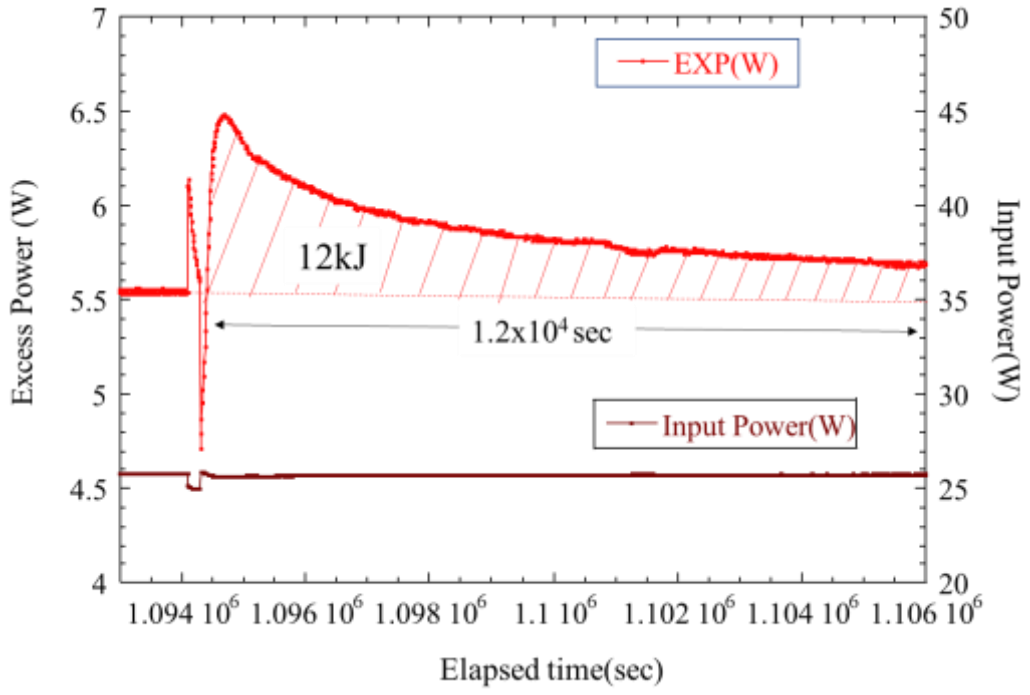

Figure 7. Released energy by a single heat burst reactions.

4. Concluding Remarks

We have been conducting research and development with an experimental method using Ni based nano-sized metal multilayer thin films with hydrogen. Anomalously large heat generation up to about 20keV/H, which was too high to be explained by known chemical reactions, was induced by heating up the metal multilayer thin film that absorbed hydrogen gas in advance.

As reported at JCF21, sudden spontaneous heat burst phenomena during excess energy generation has been observed. In this paper, we described that we succeeded in intentionally inducing such a heat burst phenomenon. An example of intentional heat burst phenomenon induced by a perturbation in input power is shown in this paper. Considering that the pressure in the chamber is less than 10^{-4} Pa, the energy released in this heat burst cannot be explained by any known chemical reactions such as hydrogen combustion. This phenomenon has been observed frequently, although it depends on the state of sample. The observation of the intentional heat burst phenomena dispelled concerns that the observed excess heat might be due to a deviation of Ni bulk calibration curve. In other words, it contributed to improving the reliability of heat measurements. We are currently investigating the conditions under which this heat burst phenomenon occurs, which is expected to contribute to the clarification of the mechanism of induced abnormal heat reactions.

Acknowledgements

The authors acknowledge Mr. H. Yoshino, Dr. T. Hioki, Mr. Y. Endo and Mr. S. Hirano who are the members of CLEAN PLANET Inc., for their significant assistance. The authors also thank Mr. Y. Shibasaki and Prof. H. Kikunaga of Tohoku University for their support. This work is supported by CLEAN PLANET Inc., Research Center for Electron Photon Science of Tohoku University Electron Photon, the Thermal & Electric Energy Technology Foundation and Tanaka Kikinzoku Memorial Foundation.

References

[1] Y. Iwamura, T. Itoh, M. Saito, S. Murakami and J. Kasagi, “Evidence for Surface Heat Release Reaction over Nano-sized Multilayer Metal Composite with Hydrogen Gas”, *Proceedings of the 21st Meeting of Japan CF Research Society*, JCF21, December 11-12, 2020, Online Meeting, p.1-14.

[2] Y. Iwamura, T. Itoh, J. Kasagi, S. Murakami and M. Saito, “Excess Energy Generation using a Nano-sized Multilayer Metal Composite and Hydrogen Gas”, *J. Condensed Matter Nucl. Sci.* **33** (2020) 1–13.

[3] Y. Iwamura, “Heat generation experiments using nano-sized metal composite and hydrogen gas”, Cold Fusion: Advances in Condensed Matter Nuclear Science, Ed. Jean-Paul Biberian, Elsevier, Amsterdam, (2020)157-165.

[4] S. Murakami, T. Itoh, Y. Iwamura, M. Saito and J. Kasagi, “Excess Energy Generation Experiments using a Nano-sized Multilayer Metal Composite and Hydrogen Gas”, Proceedings of the 20th Meeting of Japan CF Research Society, JCF20, December 13-14, 2019, Reference Hakata Eki-Higashi Rental Room, Fukuoka, Japan p.86-96.

[5] M. Saito, T. Itoh, Y. Iwamura, S. Murakami and J. Kasagi, “Elemental Analysis for Elucidation of the Anomalous Heat Generation Phenomena”, Proceedings of the 20th Meeting of Japan CF Research Society, JCF20, December 13-14, 2019, Reference Hakata Eki-Higashi Rental Room, Fukuoka, Japan p.74-85.
[6] Y. Iwamura, M.Sakano and T.Itoh, Elemental Analysis of Pd Complexes: Effects of D_2 Gas Permeation, *Jpn. J. Appl. Phys.* **41 (**2002) 4642-4650.
[7] Y. Iwamura, T. Itoh, N. Gotoh and I. Toyoda, Detection of Anomalous Elements, X-ray and Excess Heat in a D_2-Pd System and its Interpretation by the Electron-Induced Nuclear Reaction Model, *Fusion Technology,* **33 (**1998) 476-492.
[8] Y. Iwamura, T. Itoh, M. Sakano, N. Yamazaki, S. Kuribayashi Y. Terada, T. Ishikawa, D. Sekiba, H. Yonemura and K. Fukutani, Observation of Low Energy Nuclear Transmutation Reactions Induced by Deuterium Permeation through Multilayer Pd and CaO thin Film, *J. Condensed Matter Nucl. Sci.* **4** (2011) 132–144.
[9] Y. Iwamura, T. Itoh and S. Tsuruga, Transmutation Reactions Induced by Deuterium Permeation through Nano-structured Pd Multilayer Thin Film, *Current Science*, Vol. 108, NO. 4 (2015) 628-632.
[10] A. Kitamura, A. Takahashi, R. Seto, Y. Fujita, A. Taniike and Y. Furuyama, “Effect of Minority Atoms of Binary Ni-Based Nano-Composites on Anomalous Heat Evolution under Hydrogen Absorption”, *J. Condensed Matter Nucl. Sci.*, **19** (2016) 1-10.
[11] A. Kitamura, A. Takahashi, K. Takahashi, R. Seto, T. Hatano, Y. Iwamura, T. Itoh, J. Kasagi, M. Nakamura, M. Uchimura, H. Takahashi, S. Sumitomo, T. Hioki, T. Motohiro, Y. Furuyama, M. Kishida, H. Matsune, “Excess heat evolution from nanocomposite samples under exposure to hydrogen isotope gases”, *International Journal of Hydrogen Energy* **43** (2018) 16187-16200.
[12] Y. Iwamura, T. Itoh, J. Kasagi, A. Kitamura, A. Takahashi and K. Takahashi, “Replication Experiments at Tohoku University on Anomalous Heat Generation Using Nickel-Based Binary Nanocomposites and Hydrogen Isotope Gas”, *J. Condensed Matter Nucl. Sci.* **24** (2017) 191–201.
[13] Y. Iwamura, T. Itoh, J. Kasagi, A. Kitamura, A. Takahashi, K. Takahashi, R. Seto, T. Hatano, T. Hioki, T. Motohiro, M. Nakamura, M. Uchimura, H. Takahashi, S. Sumitomo, Y. Furuyama. M. Kishida and H. Matsune, Anomalous Heat Effects Induced by Metal Nano-composites and Hydrogen Gas, *J. Condensed Matter Nucl. Sci.* **29** (2019) 119–128.
[14] T. Hioki et.al, Inductively Coupled Plasma Mass Spectrometry Study on the Increase in the Amount of Pr Atoms for Cs-Ion-Implanted Pd/CaO Multilayer Complex with Deuterium Permeation, *Jpn. J. Appl. Phys.* **52** (2013) 107301.
[15] Y. Fukai, Evidence for Quantum Diffusion of Hydrogen in Ta: Quench-Recovery Experiments Revisited, *Japanese Journal of Applied Physics*, Vol.23, No.8 **(**1984) 596-598.
[16] H. Wipf, Electro- and Thermo-Transport of Hydrogen in Metals, *Hydrogen in Metals II*, Ed. by G. Alefeld and J. Völkl, Springer-Verlag, Berlin, Heidelberg (1978) 273-304.