BEHAVIOR OF PZT PIEZOELECTIC MATERIAL LAMINATED ON CARBON RELATED PLATE FOR STRUCTURE IN SPACE ENVIRONMENTAL EFFECT

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GLOSSARY

Energy harvesting, Piezoelectric effect, Space Structure, Space environment, Conductive diamond film

ABSTRACT

PZT, lead zirconate titanate (Pb[Zr(x)Ti(1-x)]O3) is expected as a potent on-site energy supply to support space mission on extraterrestrial places such the moon, mars, etc., or in huge space structure on orbit due to its mechanical-electro energy conversion from rate of deformation. Piezoelectricity commonly used to monitor the hearth of structure but reversely to collect the energy simultaneously. This research shown the feasibility of energy harvesting effect and behaviour of piezoelectric materials laminated with carbon related materials such as RO graphene etc. and evaluation how much changed the output and property of operating under the space environmental factors

1. INTRODUCTION

Since the first using of solar cell panel in 1958, the acquirement system of electrical energy from the solar source has sustained almost for half of century comparing with other achievements of space technology. Because the space environment near earth and the solar system shown with most harsh condition to operate with materials produced on ground, therefore space environments are regarded as the negative objectives to protect or to avoid for safety and stable operation of space mission. The other hand, if arranged well the system for energy harvesting, space environments are best sources to supply infinite energy for the space mission. As shown in Fig.1, a new integrated energy harvesting system from space environments are suggested as the additional energy base on the conventional solar cell panel which includes three energy harvesters, one is PZT piezoelectric energy system using the solar radiation heating, the second is the super dielectric system to induce the charged electrons for collecting usable electricity related with the PZT operation. And PZTs used on deformed or vibrated places in spacecraft. This study is progressed partially with the first described Bimetal-PZT energy harvesting system related with space environments.

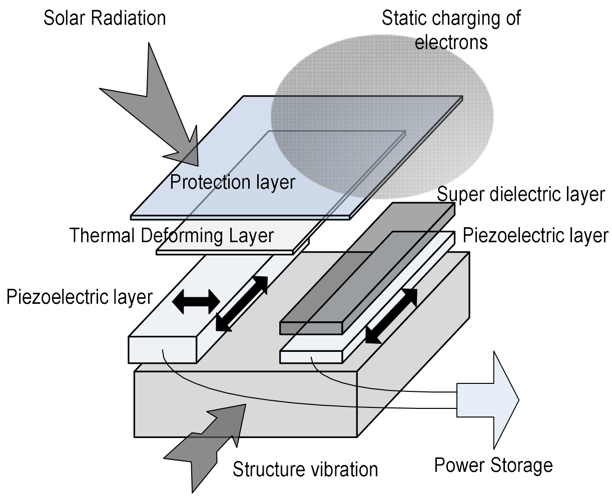

Fig1. The new integrated energy harvesting system

2. PZT PIEZOELECTRICITY

2.1. Relation of Mechanical and Electrical Factors

To understand the effect of energy harvesting using PZT, the analytic equations are commonly introduced. The total energy of PZT related to the constitutive relations for transversely isotropic piezoelectric materials (e-type) are was noted as Eq.1,

$$\begin{aligned}\{\sigma\} &= [c^E]\{\varepsilon\} - [e]^{\mathrm{T}}\{E\} \\ \{D\} &= [e]\{\varepsilon\} + [\kappa^{\varepsilon}]\{E\}\end{aligned} \quad (1)$$

where the italic superscripts, E and ε , denote a constant electric field and a condition of constant strain, respectively, and the gothic superscript, T , represents the transpose of the matrix. Thus, $\{ c_{ij}^{E} \}$ are the elastic stiffness constants measured at a constant electric field, $\{ e_{ij} \}$ are the piezoelectric stress constants, and $\{ \kappa_{ij}^{\varepsilon} \}$ are the dielectric permittivities under constant strain

The experimentally determined linear component of the potential energy, Π_l is used in this research. By using the linear terms, it can be found that

$$d\Pi_l = -\Delta_l dF - Q_l dV - G_l dA \quad (2)$$

Here, A is the crack surface area and Δ is the displacement. F, Q and V are the applied force, charge, and voltage, respectively. G is the crack driving force or energy release rate for the crack area, and the subscript, l indicates "linear". The mechanical displacement, Δ, has a linear elastic component and a remanent component. The electric charge also exhibits linear dielectric behavior and remanent polarizations. The electric charge, Q_l, and the displacement, Δ_l, are given by

$$\Delta_l = \left(-\frac{\partial \Pi_l}{\partial F}\right)_{A,V} = C_m^V F + C_p V = \Delta_l^{\mathrm{F}} + \Delta_l^{\mathrm{P}} \quad (3)$$

$$Q_l = \left(-\frac{\partial \Pi_l}{\partial V}\right)_{A,F} = C_e^F V + C_p F = Q_l^{\mathrm{E}} + Q_l^{\mathrm{P}} \quad (4)$$

where the italic superscripts, "F", "E," and "P," denote the pure mechanical and electrical contributions and the electro-mechanical (piezoelectric) contribution . Using Eqs. (3) and (4), the following relations can be found:

$$C_m^V = \left(\frac{\partial \Delta_l^{\mathrm{F}}}{\partial F}\right)_{A,V} \quad (5)$$

$$C_e^F = \left(\frac{\partial Q_l^{\mathrm{E}}}{\partial V}\right)_{A,F}, \quad C_p = \left(\frac{\partial Q_l^{\mathrm{P}}}{\partial F}\right)_{A,V} = \left(\frac{\partial \Delta_l^{\mathrm{P}}}{\partial V}\right)_{A,F} \quad (6)$$

Here, C_e^F and C_m^V are defined from the pure mechanical displacement, Δ_l^{F} and pure electric charge, Q_l^{E} instead of the total linear displacement, Δ_l and total linear electric charge, Q_l, respectively. Moreover, C_p is defined from the piezoelectric displacement or charge instead of the total linear displacement or charge. Therefore, in this study, the pure mechanical compliance, C_m^V, measured under no electric load condition, and the pure electrical capacitance, C_e^F , without mechanical effects are defined as constant and intrinsic values according to the geometric size and crack length of samples. However, the piezoelectric compliance, C_p, is a dependent variable due to electromechanical coupling effects under a combination of mechanical and electrical loads. The units are [C/V] or [F] for C_e^F, [m/N] for C_m^V, and [C/N] or [m/V] for C_p, respectively. Finally $\kappa_{ij}^{\varepsilon}$ are calculated for each materials using in space. PZT has 0.5 and kinds of polymers have 0.2, therefore PZT has higher energy release rate than other piezoelectrical materials. However it is much brittle and heavier than polymers, thus the proper design includes most efficiency is required before used in actual operation.

2.2. Bimetal-PZT Energy Harvester

The concept of schematic is shown on Fig.2 which consists of three important elements, the bimetal disc shaped circle heated by solar radiation through the collimator to concentrate the solar ray operate the connecting system having cooler for turning back to before condition applied force on the PZT plate, then it deformed till the energy stage of electrical power are initiating as much as stored in the capacitor. Aa a reference, the upper wall and bottom wall of PZT chamber will used in the next stage to yield the charging energy from static electrons on surface of super dielectric materials.

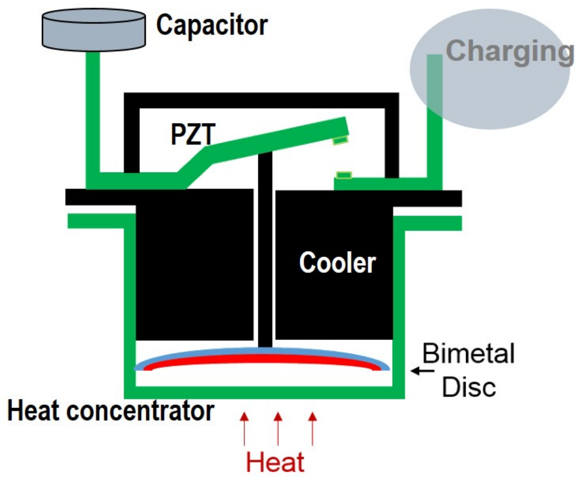

Fig.2 Bimetal-PZT energy harvesting system

Regarding the functional performance of bi-metal system, particular structure is designed considered with effects of space environments as shown in Fig.3.

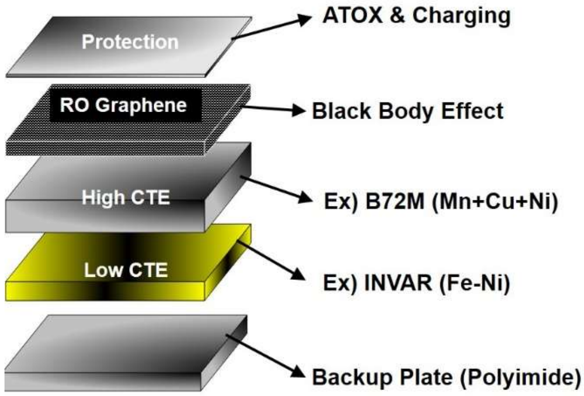

Fig. 3 Structure of the bimetal element

Utmost layer is covered with anti-ATOX and charging material such conductive diamonds, the erosion of ATOX is the most critical factor to damage the system and high charged energy of static electrons is a kind of harsh element. For increase the temperature of surface on high thermo-extensive material such as B72M, consists of Mn, Cu, and Ni, RO graphene is coated precisely. According to result of pre-experimental work, its absorptivity,α and emissivity, ε have the value of over 0.95 which is able to increase the surface temperature at least twice than those of MLI, multi layered insulator, ex) aluminized Indium coated Kapton polyimide. INVAR, consists of Fe and Ni, has a very low value of CTE, coefficient of thermal extension, it is able to shown the effective deformational energy against B72M. The lowest installed plate is selected among polymeric material to give the damping effect to control the over-operated function of bimetal.

2.3. Simulator of Solar Radiation

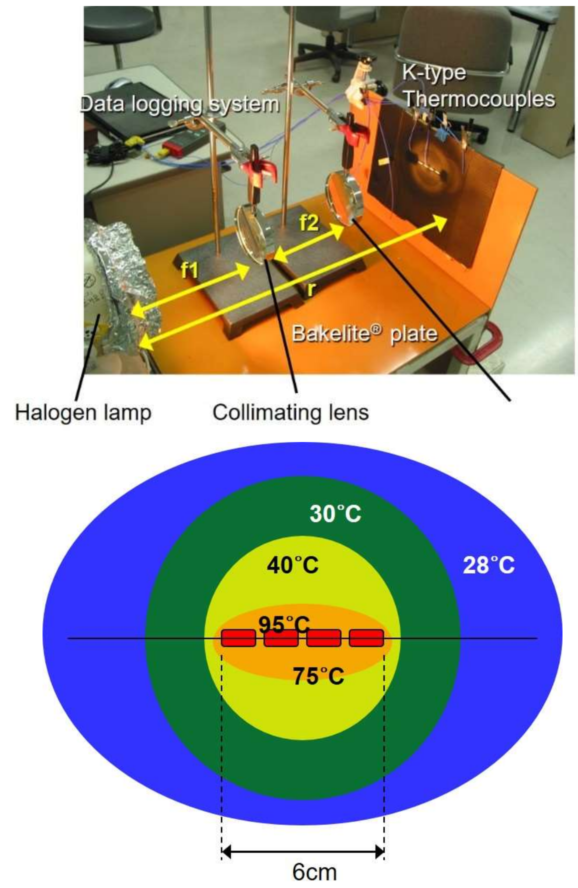

Fig. 4 Simple Simulator of Solar Radiation and Test result of heating effect using two convex lenses.

The analytic equation of thermal heating from the solar radiation is noted as Eq.7 where the temperature of wall, surface of being radiated with solar ray, T_W, is able to calculated with the absorptivity of RO graphene, α_S^{RO}, and its emissivity,ε_{RO}, the emissivity of M72M,ε_M, the solar constant G_S, 1,353 W/m^2, and Stefan–Boltzmann constant, $\sigma = 5.669 \times 10^{-8}\ W/m^2 \cdot K^4$,

$$T_W = \left[\frac{\alpha_S G_S}{\sigma \cdot (\varepsilon_{RO} + \varepsilon_M)}\right]^{\frac{1}{4}} \tag{7}$$

Using Eq.7, the temperature of surface using bimetal coated with RO graphene is calculated and shown 118 °C, normally 41 °C while coating with MLI, the multi-layered insulation. The actual experiment to measure and test the sample were progressed with a simple structured simulator for solar ray shown in Fig. 4 where a 2KW-halogen lamp and two 100 mm diameter convex lenses are utilized to collimate the focus of heating center recorded almost 100 ℃. Measuring devices are K-type thermocouples set on critical points and the infrared camera for checking the whole thermal distribution. Originally RO graphene is main material to collect the heat from the sun, but to reduce the time and effort, single walled carbon nanotubes are used, theoretically, it has perfectly same structure and function with graphene. As a results, two graphs shown in Fig.5 and Fig. 6 proven the black material such as RO graphene is expected to increase the surficial temperature of bimetal elements at least 20 ℃ higher than common materials for thermal management.

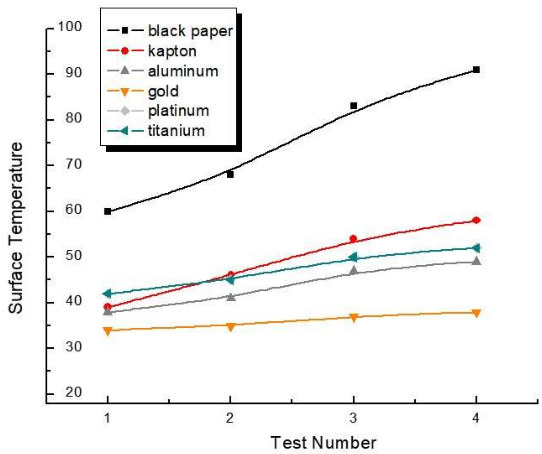

Fig. 5 Common material used in space mission tested for heating temperature

Consequently, black coating such as RO graphene, carbon nanotubes, and any flat coloured coating must be yield the over 0.9 emissivity and expected the high efficient operation of heating process. However it is required the reaction of erosion or damage from the aggressive ATOX, plasma, and hyper speed electrons drifted by the magnetic field of earth.

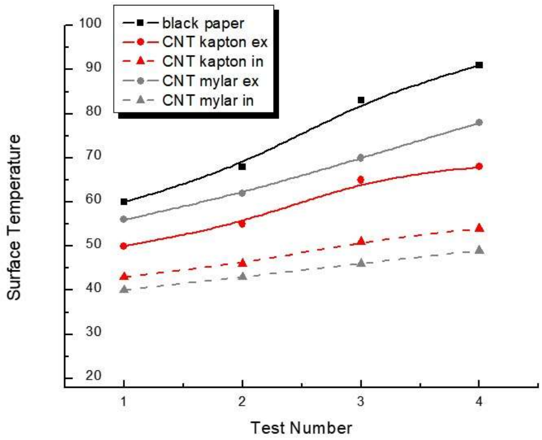

Fig. 6 Extra materials designed to increase heating temperture.

CONCLUSION

This study shows the feasibility of new energy harvesting system applying for space mission. The combination of PZT-bimetal is first function of energy harvesting and next step, charging electrons and vibrational PZT are integrated together for better and larger energy acquisition on orbit. Due to the beginning stage of long-term study, it was acquired partial data and remained many uncertain factors. According to theoretical simulation with collaborated reports, this system is anticipated to support the conventional solar cell panel adding 20% of energy saving efficiency.

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