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Cyclic heating system to explore pyroelectric Performance

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----------*ABSTRACT*----------
A cyclic heating system to periodically heat and cool the pyroelectric samples to explore their performance has been designed. Different heating and cooling cycles ranging from 1-3 seconds was applied to $BaTiO_3$ and PZT. It is found that the temperature increases rapidly for high heating cycles in $BaTiO_3$ for the obvious reason. Also, the temperature does not drop back to initial temperature as there is no external cooling resulting in cumulative heating of the samples. It is seen that after certain number of cycles, the samples come to their equilibrium state and the temperature becomes almost constant. The steady state is achieved by BaTiO3 and PZT in around 9 and 15 seconds respectively. BaTiO3 sample gains equilibrium faster as compared to PZT sample because of its higher heat capacity. It is interesting that the gradient peaks for BaTiO3 are maximum for 3 second cycles while in PZT it was observed for 1 second cycle because of their conductivities. It was found that for BaTiO3 the maximum induced dynamic pyroelectric current was obtained for 3 second of heating cooling cycle because of higher absorption of heat in same time duration
KEYWORDS: *Energy harvesting, Pyroelectric, BaTiO3, PZT*

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I. INTRODUCTION

As a consequence of increasing energy crisis energy harvesting has currently become a topic of intense interest. Coal, oil and natural gas in all meet around 80% of the global energy requirement. Therefore, to bridge this demand-supply gap, researchers are actively investigating the alternative sources of energy which are sustainable[1–5] .Tidal, wind and solar are one of the most common alternative sources of energy of renewable energy. In the surroundings, thermal energy is ejected from almost all the physical systems in the form of low grade energy which needs to be harvested. Different methods like thermoelectric, solar power plants and photovoltaic cells have been devised to convert the thermal energy into electric energy[6]. Recently, pyroelectric materials have gained popularity in the research community for energy harvesting capabilities. These are the class of materials which produce electricity when subjected to temporal temperature gradient[7]. In addition, pyroelectric materials are well known for their actuation and sensing applications.

Pyroelectric materials have the potential to function with high thermodynamic efficiency when compared to thermoelectric generators and do not need large heat sinks to maintain the temperature gradient. Pyroelectric materials react to temporal temperature gradient which causes an internal strain and this, in turn, results in electrical charges on the material's surface. Advances in materials and in thermal-electrical cycling methods are predictable to provide low cost and high-power-density electrical generators[8]. Pyroelectric element when subjected to a power density radiation (W) causing a temperature variation (dT) the induced charge (dQ) released by the electrode area (A) of the element due to a decrease in polarization is given as: [7], [9].

$$dQ = \eta P A dT \qquad (1)$$

where η is the absorption coefficient of radiation and P (units: $\mu Cm^{-2} K^{-1}$) is the pyroelectric coefficient of the pyroelectric material.

$$P = \frac{dP_S}{dT} \qquad (2)$$

$$i_p = \eta P A \frac{dT}{dt} \qquad (3)$$

where P_s is the magnitude of the electrical polarization vector and $i_p$pyroelectric response current. Pyroelectric materials, such as flat-plate capacitors are sandwiched in between the top and bottom electrodes and poled along the axis perpendicular to the plates. P_s is perpendicular to the electrode surface and its magnitude is given as electrode charge density. Pyroelectric materials with high P value are considered for applications. Also, increasing the electrode area will be result in enhanced current under parity of incident thermal power density per unit area. It is difficult to experimentally determine the temperature gradient therefore finite element modeling is done to explore the temperature variation rate in pyroelectric materials with some

designs of cavities created by wet etching, trenches made with a precision dicing saw, and grooves generated by a sandblast etching technique, in order to improve the energy conversion efficiency of $BaTiO_3$ and PZT cells by pyro-electricity [10–12]. Cyclic heat energy harvesting mostly is used to convert temperature gradient into electricity. Periodic heating leads to continuous power generation over time and provides a means of continuously harvesting energy. It is necessary to design a periodic temperature profile and apply it to the pyroelectric elements to generate temperature variation rates. The factors affecting the periodic temperature profiles for improving the temperature variation rate in pyroelectric elements include the frequency or work cycle, radiation power, properties and dimensions of the air layer, and the material properties, dimensions and structure of the pyroelectric elements, etc.

The rest of the paper is organized as follows. Material and methods used are explained in section II. Experimental results and discussion is done in section III. And final conclusion is in section IV.

II. MATERIALS AND METHOD

In the present study, the pyroelectric performance of BaTiO3 and PZT has been explored using finite element method. For this purpose, finite element simulations were carried out. As a starting point, the transient heat transfer is carried out analysis to find out the temperature variation in the materials with temperature and other parameters. For the analysis purpose, cylindrical samples were considered with diameter of 24 mm and thickness of 3 mm as shown in Fig.1. The material properties are provided in Table 1.

Table-1 Material properties

Sample	**Thickness (mm)**	**Area $(mm)^2$**	**Pyroelectric coefficient ($\mu C/m^2K$)**	**Specific heat ((J/(gK))**	**Thermal conductivity (W/(mK))**	**Density (g/cm^3)**
$BaTiO_3$	3	452	200	0.434	2.85	5.94
PZT	3	452	557	0.348	0.14	7.6

The temperature variation in samples is governed by the following differential equation:

$$\rho C_p \frac{\partial T}{\partial t} - \nabla.(k\nabla T) = Q \qquad (4)$$

Where ρ, C_p, k and Q are density, specific heat at constant pressure, thermal conductivity and heat flux respectively.

Here, the sample has been simulated in axially symmetric configuration i.e. the rotation of rectangular domain has been considered about the vertical axis as presented in fig.1. The bottom and side edges of the samples were exposed to room temperature in simulations while the periodic heat flux was given on the top surface. A heat flux of 50 W was given with different on off cycles and average variation in temperature on top surface of sample is monitored. At later stage, this temperature variation is related to the dynamic pyroelectric response current using equation 3.

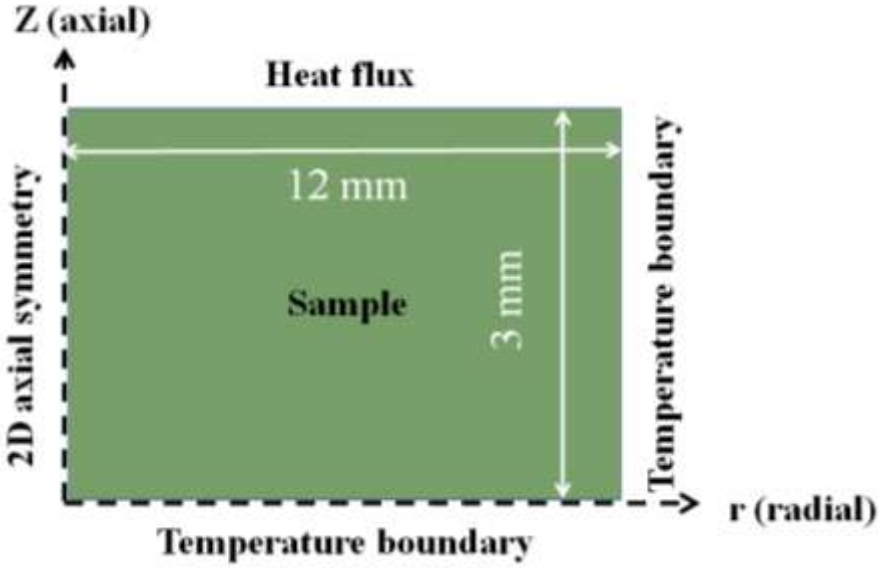

Fig.1. Cylindrical sample

III. RESULTS ANDDISCUSSIONS

Here, the cyclic heating system is designed to periodically heat and cool the samples so as to explore their pyroelectric performance. It is to be noted that with periodic heating the temperature change is smaller, however, over the time temperature change becomes higher and so the harvester energy [15]. As a starting point, different heating and cooling cycles of 1, 2 and 3 seconds were applied to $BaTiO_3$ and PZT. It is found that in $BaTiO_3$ the temperature increases rapidly for high heating cycles for the obvious reason. In addition, it is to be noted that for the same duration of cooling cycle the temperature does not drop back to initial temperature as there is no external cooling. This results in cumulative heating of the samples over the time as shown in fig. 2. However, similarity is not observed in PZT in terms of temperature rise with heating cooling cycles Owing to its lower thermal conductivity PZT is not able to dissipate heat as fast as it gains so for smaller duration of cycles its temperature increases at a higher rate. It can be seen that after certain number of cycles the samples come to their equilibrium state and the temperature becomes almost constant. The steady state is achieved by BaTiO3 and PZT in around 9 and 15 seconds respectively. BaTiO3 sample gains equilibrium faster as compared to PZT sample because of its higher heat capacity. After this, the temporal gradient of temperature was computed as presented in fig 3. It is interesting that the gradient peaks for BaTiO3 are for maximum 3 second cycles while in PZT it was observed for 1 second cycle because of their conductivities.

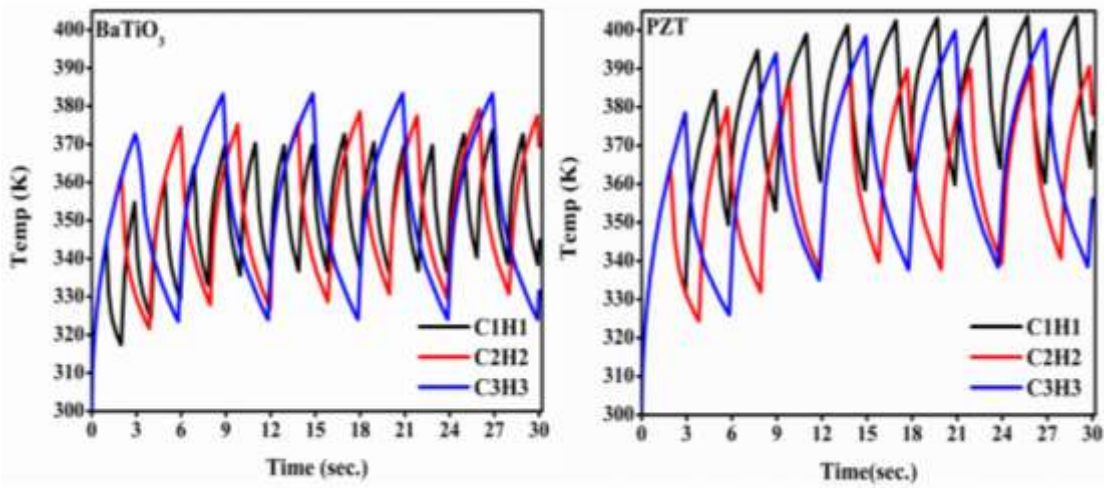

Fig.2. Cumulative heating of the samples over the time

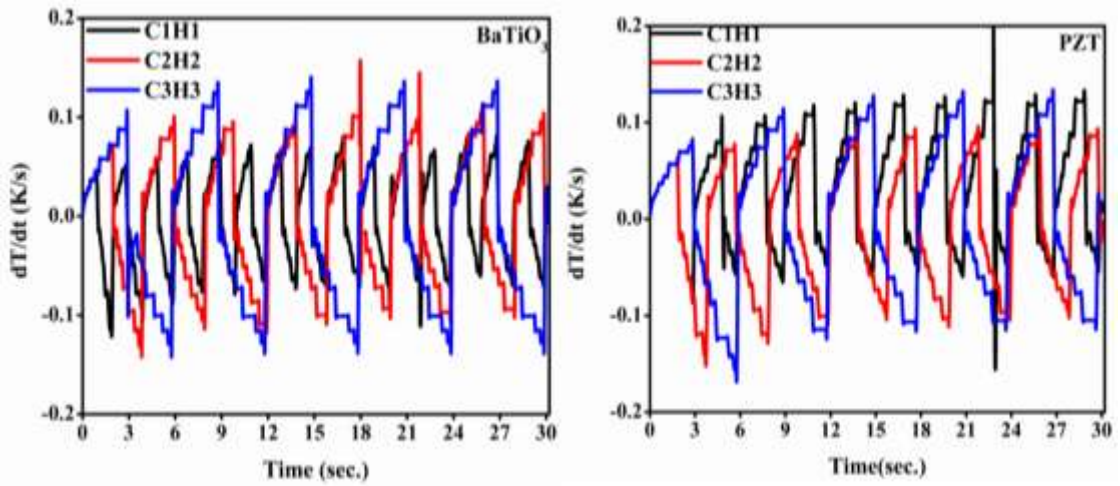

Fig.3. Temporal gradient of temperature

It is to be understood that upon being subjected to temporal temperature gradient charge (Q) is induced on the electrode area. This charge (Q) can be calculated in accordance with equation 1.Charge collected on the electrode area was computed for different cycles for both the samples. It can be observed from fig.4 that for corresponding cycles the charge collected on the surface was much higher for PZT sample because of its higher pyroelectric coefficient. In addition, highest peaks were observed for heating cooling cycles of 2 seconds each because of high temperature gradient obtained. One step ahead, dynamic pyroelectric current response due to

induced charge was also computed using equation 3 as shown in Fig. 5. It was found that for BaTiO3 the maximum induced dynamic pyroelectric current was obtained for 3 second of heating cooling cycle because of higher absorption of heat in same time duration. On the other hand, because of lower thermal conductivity peaks were observed for 1 second cycle.

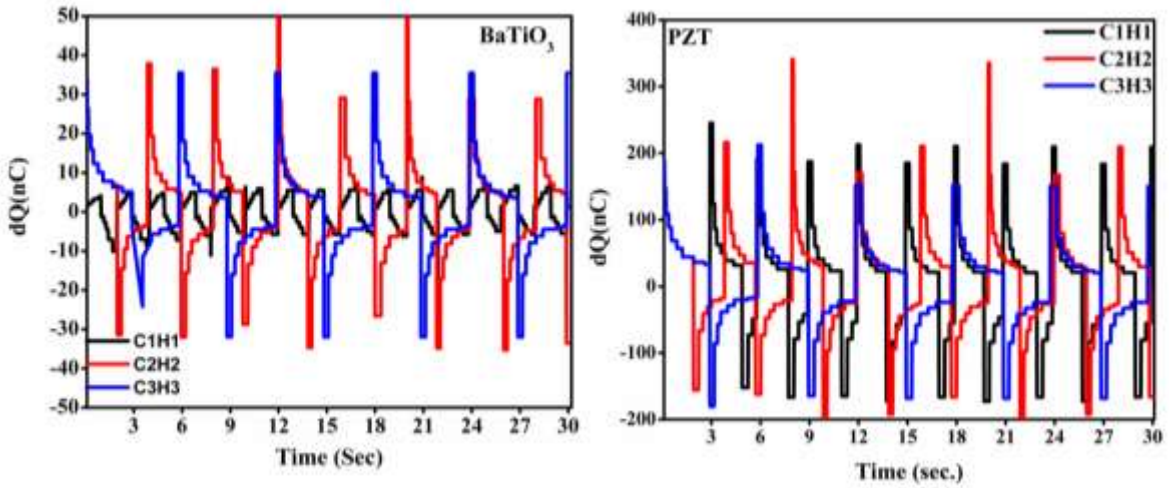

Fig.4. Charge collected on the surface

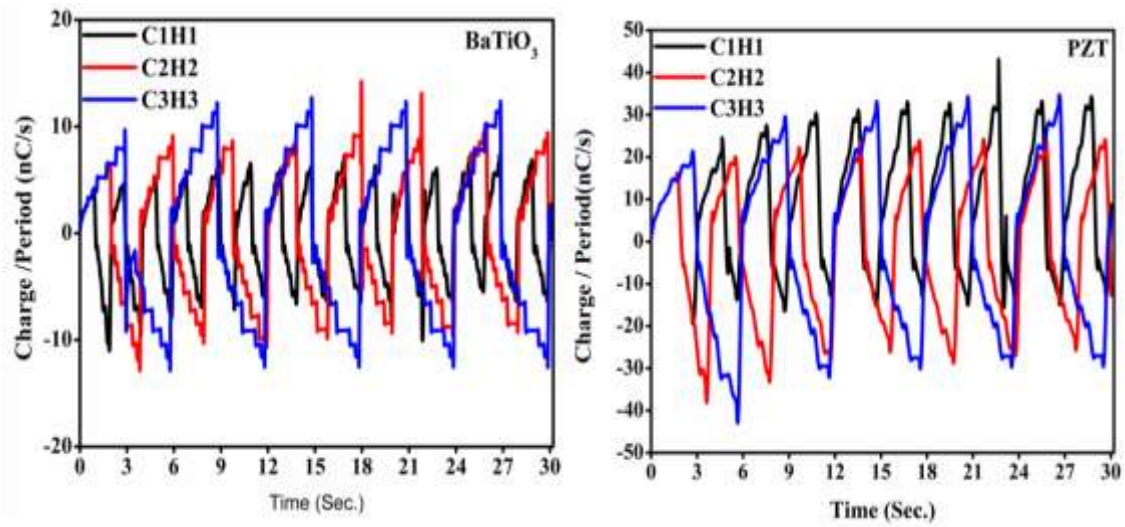

Fig.5. Dynamic pyroelectric current response

IV. CONCLUSION

In the present scenario with increase in demand of energy it is required to have an alternate energy harvesting system. Form the above discussion it can be concluded that materials like to $BaTiO_3$ and PZT can serve the purpose of energy harvesting. PZT is found to have high charge collected on the surface where as for BaTiO3 the maximum induced dynamic pyroelectric current was obtained. Finally it is concluded that that materials with property of higher absorption of heat and lower cooling at some extent can be used for energy harvesting.

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