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# Designing of Micro Electrocaloric Cooling System

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***Abstract*—Chip size cooling system is critical for the development of electronics with increase of power consumption and reduction of size result in demand of novel cooling system for thermal management. Usually chip is cooled by natural convection, but the excess heat produced damages the chip. A proper forced cooling system can increase the performance as well as the life of the chip. Larger chips uses fan as a medium of cooling which need additional power. It's not possible to have fan for each chip. In-build forced cooling system can help to overcome these difficulties. This paper suggest a novel system using electrocaloric effect. The electrocaloric effect is a phenomenon in which a material shows a reversible temperature change under an applied electric field. The electrocaloric material used is Poly(Vinylidene Fluoride-Trifluroethylene-chlorofluoroethylene) [P(VDF-TrFE-CFE)] which is a terpolymer. The electrocaloric effect is produced due to the electric field from chip. The heat produced by the chip is absorbed by the electrocaloric material to carry out the electrocaloric effect. The heat absorbed is transferred to the sink using a heat transfer fluid. The novel design of chip and cooling system was made based on the numerical calculation. The size depends upon the type of the chip used. The system size is found to be 1.6mm height 10mm length and 7 mm width.**

***IndexTerms*—Electrocaloric, refrigeration, chip cooling.**

## I. Introduction

Micro-scale refrigeration system have a wide range of potential application such as cooling of integrated circuits, MEMS sensors, radio frequency electronics and biomedical devices. With development of MEMS technologies and semiconductors, power consumption has increased significantly while device size has reduced substantially, resulting in an emergent demand on dissipating a high heat density. Novel cooling technologies with high efficiency are attractive due to growing energy consumption and the requirement of thermal management. In recent years, novel solid-state cooling technologies, such as electrocaloric and magnetocaloric cooling have attracted interest. The current cooling system in an integrated circuit(IC) is just natural convection of cooling which reduced the temperature much less compared to forced convection. So a forced convection cooling system for IC is much needed.

### A. *Principle of electrocaloric refrigeration*

#### 1) *Electrocaloric Effect*

The EC effect refers to a reversiblechange in the temperature of a dielectric material upon the application or removal of an electric field. It is analogous to the heating or cooling of a gas upon adiabatic compression or expansion. The converse effect, pyro electricity, has been widely studied for infrared imaging and energy harvesting applications.

When an electric field is applied to an EC material, the material becomes more polar-ordered, reducing the entropy associated with polarization. If this process occurs under reversible adiabatic conditions, the total entropy of the material remains constant. The remaining components of the entropy (hence the temperature) must then increase to compensate for the decrease in the polarization entropy. The converse is true if the material becomes less polar-ordered upon removal of the electric field. The material must then cool down to compensate for the increase in the polarization entropy. This is the basis of EC cooling.

Although the EC effect was first reported by Kobeco and Kurtschatov in 1930,potential applications have been limited by the relatively low entropy and temperature changesfor most ferroelectric materials. Recently, materials with a large EC effect have been discoveredby A. Mischenko et al.[1] and Bret Neese et al [2], suggesting practical applications in cooling devices.

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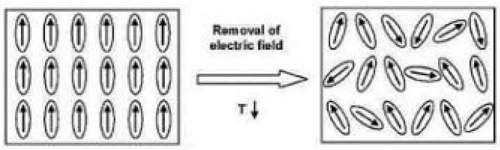


Fig 1. Conceptual macroscale illustration of the mechanism of the electrocaloric cooling effect

2) *Thermodynamic Cycle*

As in vapour compression cycles, different thermodynamic cycles can be used to exploit the EC effect for refrigeration. Alternative cycles developed for pyroelectric energy conversion may also be adapted for EC cooling. Figure 2 schematically illustrates another possible cycle on a *T-S* diagram, which is more straightforward to implement. The cycle consists of the following: (1) polarization step: from state A to state B, the EC material experiences electrocaloric heating as the electric field is raised adiabatically; (2) heat rejection step: the material subsequently rejects heat under the constant electric field to reach state C; (3) depolarization step: from state C to state D, the material experiences electrocaloric cooling as the electric field is reduced adiabatically to its minimum value; (4) heat absorption step: the "cold" EC material is then brought into thermal contact with an electronic device to absorb heat under the constant electric field and returns to state A

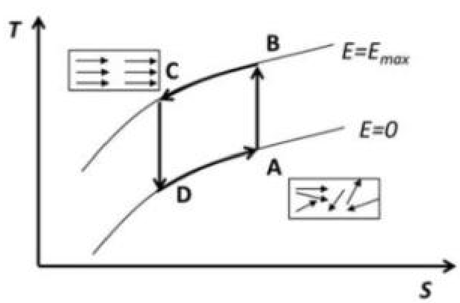


Fig 2. T-S diagram for an electrocaloric material

3) *Related Works*

Jia and Ju [3] proposed a design of a solid-state refrigeration system based on the ECeffect where an EC material is dynamically moved by a motorized z-stage between a heat sourceand a heat sink.

Dongzhi Guo et al. [4] proposed a design based on electrocaloric effect using the movement of PDMS diaphragm and working fluid.

This journal consist of designing of novel chip cooling system that works on electrocaloric effect.

## II. GOVERNING EQUATIONS

The fluid flow is incompressible and described by the Navier-Stokes equations. The energy equation within the electro caloric material is

$$.\rho c \frac{\partial T}{\partial t} = k\nabla^2 T - \dot{Q} \qquad (1)$$

where T is the temperature and t is time $\dot{Q}$ is the heat source term due to the effect of electrocaloric effect of the material which is described by

$$\dot{Q} = \rho T \left(\frac{\partial S}{\partial E}\right)_T \frac{\partial E}{\partial t} \qquad (2)$$

where S is the entropy and E is the applied electric field [5]. While the relationship between entropy and electric field is generally temperature-dependent, the EC effect of this terpolymer does not demonstrate a large deviation when the temperature changes from 270 K to 320 K. Therefore, the entropy change is assumed to be temperature independent for simplicity within this temperature range. We note that the reported dielectric loss of the terpolymer is small and is ignored in the modelling.

A. *Dielectric displacement*

The full mechanism of the electrocaloric effect is not yet fully understood as is the case with the magnetocaloric effect, although similarities between the two exist. Christo Ananth et al. [6] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased. The specific electric work that is applied to a system of electrodes and dielectric (electrocaloric) material is defined as:

$$dw = -E.\,dD \qquad (3)$$

where E represents the electric field and D is the electric displacement field. The electric displacement field D is a combination of the electric field E and the electric polarization of the material P.

$$D = \varepsilon_0 E + P \qquad (4)$$

If we consider a reversible thermodynamic process, constant volume and pressure (and therefore no pressure or volume work in the electrocaloric material) the equation for the specific internal energy u of the electrocaloric material can be simplified to:

$$du = Tds + EdP \qquad (5)$$

B. *Specific enthalpy*

From the engineering point of view the enthalpy is one of the most important thermodynamic potentials. The enthalpy describes the behaviour of an open thermodynamic system with the work performed over its boundary. It can be defined by applying Legendre transformations to the first law of thermodynamics. The specific enthalpy of dielectric/electrocaloric material is defined as:

$$h = u - EP \qquad (6)$$

The derivative of this potential is:

$$dh = du - PdE - EdP \qquad (7)$$

Inserting Eq. (5) into Eq. (7) it follows that:

$$dh(s, E) = Tds - PdE \qquad (8)$$

We can rewrite the Eq.(8) as

$$dh(s, E) = \left(\frac{\partial h}{\partial s}\right)_E ds + \left(\frac{\partial h}{\partial E}\right)_s dE \qquad (9)$$

Using the partial derivatives from Eq. (9) and the Maxwell relation it also follows that:

$$\left(\frac{\partial h}{\partial s}\right)_E = T \qquad (10)$$

$$\left(\frac{\partial h}{\partial s}\right)_E = P \qquad (11)$$

$$\left(\frac{\partial T}{\partial E}\right)_s = -\left(\frac{\partial P}{\partial s}\right)_E \qquad (12)$$

In a constant electric field (i.e., an isofield process), the derivative of the specific enthalpy equals to

$$dh = dq = Tds \qquad (13)$$

The specific enthalpy (h) at a constant electric field is defined as:

$$h = h_0 + \int_0^T \left(\frac{\partial h}{\partial T}\right)_E dT \qquad (14)$$

## III. SYSTEM DESIGN

In earlier section it is given that integrated circuits(IC) have natural cooling. Natural cooling will cools the IC very slowly, which may leads to the damage of the IC. So a forced convection cooling is need to remove the heat more fast/rapidly from the IC. As the size of IC is much less compared to the processor of a computer, it will be difficult to forced convection cooling without much power loss. Now when matter of power loss comes to effect. The only way power loss can be reduced is that making a system that work based on the power produced by the IC. Here comes the importance of the electrocaloric cooling system. Elelctrocaloric cooling system works based on the electrocaloric effect. The EC effect refers to a reversible change in the temperature of a dielectric material upon the application or removal of an electric field.Considering the other IC's DIP is comparatively larger. So we prefer DIP [7] as the IC in the project. As shown in the table, the length is about 9.8mm and width is about 6.48mm. The heat generated in an IC is based on Joule Heating and it's found to be about in the range of 223-228k. Now this will be the initial temperature of my system.

As we know the system work on electrocaloric effect, when an electric field is applied material's dielectric moment changes and align in the direction of electric current. During this process occur heat is rejected/absorbed based on the property of the material. When the alignment changes this process is called polarization. And when it goes back to its original alignment it is called depolarization.

The main components of the systems are:

- EC layer
- Heat transfer fluid
- Heat sink
- Insulator

EC layer for absorbing the heat generated in the IC, using the electrocaloric effect. The heat generated from the IC is absorbed by the EC layer when the material is in polarized form. The heat absorbed by the EC material is transferred into a heat transfer fluid. The heat transfer fluid transfer this heat to the heat sink. The insulator is kept between the EC

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layer and heat sink so that direct heat transfer between two layers does not take place. Heat transfer is passed through a microchannel present inside the system.

## IV. MATERIAL AND WORKING FLUID SELECTION

In previous section different component and its working was described. In this chapter the material and working fluid used in different component are found out.

### A. *Selection of EC material*

Electrocaloric materials can be divided into 3 groups

- Monocrystals (bulk samples),
- Ceramics (bulk samples (with thickness greater than 100 mm), thick film ceramics (with thickness greater than10 mm) and thin film ceramics (with thickness of less than 1 mm)),
- Polymers (thick and thin films)

The main obstacle to the mechanical robustness of an electrocaloric material is its long-term exposure to relatively large changes of electric field. This leads to large stresses in the internal structure, which causes an electromechanical breakdown that is analogous to fracture in elastic solids. The above-mentioned phenomena can also occur due to chemical degradation. It is related to many mechanisms, depending on the electrocaloric material and its size. Bulk samples and monocrystals cannot withstand such stresses because they have relatively low dielectric strengths. Therefore, smaller (compared to thin films) electric field changes can be applied, which consequently leads to small entropy and temperature changes in such materials.

Larger electric field changes can be applied to polymer thin films or to ceramic thin films that have the same composition as their bulk counterparts. It can be seen that thin and thick film materials can withstand much larger changes in the electric field, i.e., at least 2 or 3 orders larger compared to bulk samples and monocrystals. This is due to their much larger dielectric strength. Therefore, more promising results with larger electrocaloric effects were reported for thin-film materials. It is known that the largest entropy and temperature changes occur close to the material's Curie temperature. Most of the present electrocaloric materials have their Curie temperatures above room temperature. Polymer thin films clearly offer the largest entropy and temperature changes of all the electrocaloric materials.

The main criterion of EC material should be that it should show EC effect at a temperature range from 223-233k. Also, it should have a larger entropy change. In the table below is given the EC material which has satisfied the above criteria.

TABLE I. EC MATERIAL AND THEIR PROPERTIES

| EC material | $T^a$ K | ΔT K | ΔS J/KgK | ΔE V/m |
|---|---|---|---|---|
| PMN-0.5PT | 333 | 0.4 | .028 | 1 |
| P(VDF-TrFE-CFE) (59.2/36.3/7.2)[8] | 328 | 12 | 55 | 307 |
| BT[9] | 333 | 701 | 10.1 | 80 |
| $(NH_2CH_2COOH)_3.H_2SO_4$ | 323 | .0.11 | - | 0.4 |
| PLZT 8/65/35[10] | 318 | 40 | 5.0 | 120 |

In the above table we can see that $T^a$ is the temperature at which the material shows electrocaloric effect, ΔT is the temperature difference occur when EC effect take place, Δs is the change in entropy and ΔE is the electric field intensity of the material. The ratio between change in entropy and electric field intensity shows that how good the material can absorb or reject temperature. Also larger the temperature to electric field intensity ratio the better the EC effect. From table we can clearly see that Terpolymer P(VDF-TrFE-CFE) shows better ratios compared to other material. So we can say that using P(VDF-TrFE-CFE) can cause some effect on cooling the IC.

1) Numerical Analysis of EC material

From the table we get the electric field intensity of P(VDF-TrFE-CFE) as 307 V/m. We know that heat loss occur in an IC

$$\text{Heat Loss,}Q = \frac{T_{IC}-T_{atm}}{r_{th}} \quad (15)$$

where $T_{IC}$ is the temperature produce from IC (328K), Tatm is the atmospheric temperature (303K) and $r_{th}$ is the thermal resistivity. Thermal resistivity depend on the size of IC used and the purpose of using. The thermal resistance vary from 20-60 K/W. It was found that heat loss occur in the range of 0.45-1.40W and mean value is 0.93W

We can write heat loss Q as

$$Q = I^2R = \frac{V^2}{R} \quad (16)$$

where V is the voltage across the IC and R is the electrical resistance offered in IC. The resistance offered by IC is 60-140Ω. From Eq. 16 it was found that the voltage needed to produce 0.93 W is about 7.46-11.41V.

Electric field intensity E,

$$E = \frac{V}{d} \quad (17)$$

where d is the distance between two points where voltage occur. For the obtained voltage the electric field intensity is about 761V/m and 1164 V/m respectively. For the values it is clear that the electric field produce from IC can polarize the P(VDF-TrFE-CFE) . As the electric field intensity of P(VDF-TrFE-CFE) is only 307V/m.

B. *Heat sink material*

With the increase in heat dissipation from microelectronic devices and the reduction in overall form factors, thermal management becomes a more and more important element of electronic product design. Heat sinks are devices that enhance heat dissipation from a hot surface, usually the case of a heat generating component, to a cooler ambient, usually air. For the following discussions, air is assumed to be the cooling fluid. In most situations, heat transfer across the interface between the solid surface and the coolant air is the lead efficient within the system, and the solid-air interface represents the greatest barrier for heat dissipation. A heat sink lowers this barrier mainly by increasing the surface area that is in direct contact with the coolant. This allows more heat to be dissipated and/or lowers the device operating temperature. The primary purpose of a heat sink is to maintain the device temperature below the maximum allowable temperature [11].

1) *Heat sink selection procedure*

In selecting an appropriate heat sink that meets the required thermal criteria, one needs to examine various parameters that affect not only the heat-sink performance itself, but also the overall performance of the system. The choice of a particular type of heat sink depends largely on the thermal budget allowed for the heat sink and external conditions surrounding the heat sink. When selecting a heat sink, it is necessary to classify the air flow as natural, low flow mixed, or high flow forced convection. The next step is to determine the required volume of a heat sink. The volume of a heat sink for a given flow condition can be obtained by dividing the volumetric thermal resistance by the required thermal resistance. The average performance of a typical heat sink is linearly proportional to the width of the heat sink in the direction perpendicular to the flow, and approximately proportional to the square root of the fin length in the direction parallel to the flow.

2) Heat sink selection

From the above selection procedure, we can see that the air flow occurs in the system is natural. The fluid transfer the heat into the heat sink and this transfer to the atmosphere. The second step is the volume of heat sink required for the calculation in the previous section it was found that 0.93 W is produced as heat loss. The maximum thermal resistance is 60 K/W we get that the volume is about 7.74mm$^3$. Heat sink will be a stamping type. So when the stamping type heat sink is selected the heat sink material should be Copper or aluminium.

C. *Thermal insulator*

Thermal insulation is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence. Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials. Heat flow is an inevitable consequence of contact between objects of differing temperature. Thermal insulation provides a region of insulation in which thermal conduction is reduced or thermal radiation is reflected rather than absorbed by the lower-temperature body.

Insulation performance is influenced by many factors the most prominent of which include:

- Thermal conductivity ("k" or "λ" value)
- Surface emissivity ("ε" value)
- Insulation thickness
- Density
- Specific heat capacity
- Thermal bridging

It is important to note that the factors influencing performance may vary over time as material ages or environmental conditions change.

Thethermal insulator that can work in our temperature range is glass fiber. It shows that glass fiber has temperature range from 273k -600k and the k factor is about 0.037 W/mK.

D. *Selection of working fluid*

There has been a concern over the type of heat transfer fluid that must be used in microchannel so that the heat can be easily transferred from EC layer to sink. The heat transfer

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fluid should not react with any material used material. Also they should be electrical insulator. As we told earlier the maximum temperature a DIP can produce is in range of 218-228K. It was found that three fluid can work in our range. For a heat transfer fluid thermal penetration depth should be more.

Penetration Depth [12]

$$\delta = \sqrt{\frac{2k}{2\pi f \rho c}} \qquad (18)$$

Where k is thermal conductivity (W/mK), f frequency of electric current (Hz), ρ is density of fluid (kg/m$^3$), c is the specific heat (J/kg K).

TABLE II. TYPES OF WORKING FLUID AND THEIR PROPERTIES

| Fluids | k | ρ | c | δ |
|---|---|---|---|---|
| | Kg/m$^2$ | Kg/m$^3$ | J/KgK | m |
| HT55[14] | 0.65 | 1650 | 970 | 5.08X10$^{-5}$ |
| Therminol 55 | 0.65 | 875 | 695 | 8.24X10$^{-6}$ |
| Dowtherm | 0.75 | 975 | 791 | 7.86X10$^{-6}$ |

It was found that of the three heat transfer fluid HT 55 has the maximum thermal penetration depth. Also HT 55 is electrical insulator and will not react with any working material.

## V. MICROCHANNEL DESIGNING

Micromachining technology has been used to develop a number of microfluidic systems in silicon, glass, quartz, or plastics. Microchannels and chambers are the essential part of any such system. Christo Ananth et al. [6] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller. This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

In addition to connecting different devices, microchannels are also used for reactant delivery, as biochemical reaction chambers, in physical particle separation, in inkjet print heads, and as heat exchangers for cooling computer chips. In the design of microchannels, the basic geometrical parameters are often conditioned by the microfabrication techniques available for the microchannel manufacturing. Today, many techniques lead to the fabrication of microchannels with a rectangular cross-section. The different geometrical parameter of such microchannels are few: the channel depth, width and length, as well as the topographical shape.

The heat transfer rate of the fluid depend on the surface area of microchannel. So designing of microchannel has great important in this paper.

TABLE III. CLASSIFICATION SCHEME OF MICROCHANNEL

| | |
|---|---|
| Conventional channels | Dh > 3mm |
| Minichannels | 3 mm ≥ Dh > 200 µm |
| Microchannels | 200 µm≥Dh > 10 µm |
| .Transitional Microchannels | 10 µm≥Dh > 1 µm |
| Transitional Nanochannels | 1 µm≥Dh > 0.1 µm |
| Molecular Nanochannels | 0.1 µm ≥Dh |

From the above table [13] it is clear that for a channel to be stated that microchannel channel its hydraulic diameter (Dh) should be between 200µm and 10µm. In current scenario the only value that we know is the heat loss from the chip (0.93 W). So we need to create a microchannel so as to remove the heat produced by chip.

The assumption made are the hydraulic diameter ($D_h$) is 100µm and velocity (v) as 1 m/s.

Using Prandtl number, Reynold's number and Nusselt number for the values of heat transfer fluid it was found that the for 100µm a heat transfer of 0.0216 W will be take place for a single channel. So to transfer 0.93 W of heat, approximately 45channels required. It is not possible to make 45 channel in small system. The below table show heat that can be transferred and the number of channels for each hydraulic diameter ($D_h$).

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TABLE IV. HEAT PRODUCES FOR DIFFERENT SIZE OF MICROCHANNEL

| $D_h$ µm | Pr | Re | Nu | h $W/m^2K$ | Q W | Channels |
|---|---|---|---|---|---|---|
| 100 | 0.125 | 2000 | 11.92 | 77480 | 0.021 | 45 |
| 150 | 0.125 | 3000 | 15.56 | 68754 | 0.042 | 23 |
| 200 | 0.125 | 4000 | 18.83 | 61197 | 0.068 | 14 |
| 500 | 0.125 | 10000 | 34.49 | 44829 | 0.313 | 4 |
| 950 | 0.125 | 18000 | 52.67 | 36037 | 0.910 | 1 |
| 1000 | 0.125 | 20000 | 54.48 | 35412 | 0.991 | 1 |

From the table it can be seen that for a Dh of 150µm, heat of 0.0425 can be transferred. So for transfer of 0.93 W of heat about 23 channels need to be made.

## VI. RESULT AND DISCUSSIONS

In this section the design and the position of system will be discussed.

### A. *Design*

In previous sections we have discussed the different material and working fluid that are used in the system. From the study it was found that P(VDF-TrFE-CFE) is the EC material that we can use as it has an ability to polarize at lower electric field. Thickness of EC material is important as the thickness increases the EC effect will reduce. So here the 0.75mm is taken as the thickness of EC material.

The next important part is the sink, it is made of copper. As copper has best thermal conductivity. The thickness of heat is also 0.75mm. An insulator of 0.1mm thickness is kept so as to avoid the direct contact of EC material and heat sink. For the transfer of heat from EC material to heat sink, a heat transfer fluid HT55 is passed through a microchannel of width and height 150 µm.

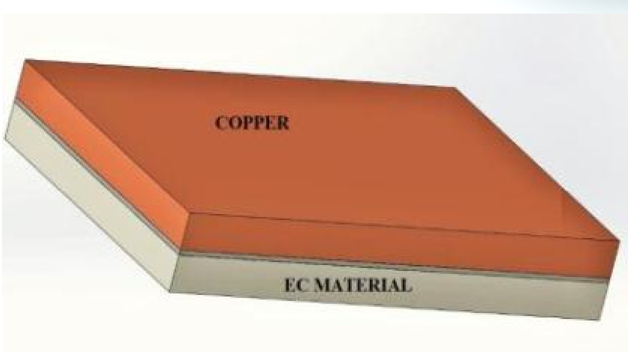


Fig 3. Novel EC cooling system

In Fig 2. The top part the heat sink and the bottom part is the EC material. The total thickness of the system is about 1.6mm. Length and width of system is that of a chip i.e., 10mm and 7mm respectively. The wireframe figure (Fig 3.) shows that it contain 23 microchannel for the flow of heat transfer fluid.

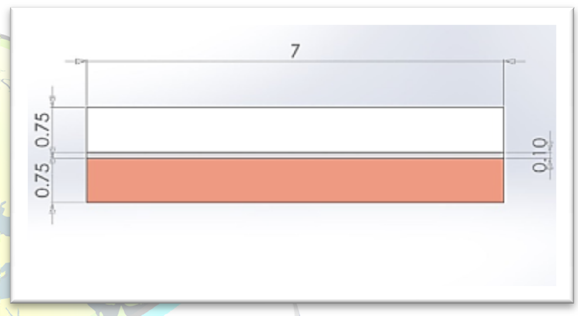


Fig 4. Front view of EC cooling system with dimension in mm

### B. *Position of system*

The position of system is also important when considering the designing of an IC cooling system. As the system can be kept either on bottom of IC or top of IC.

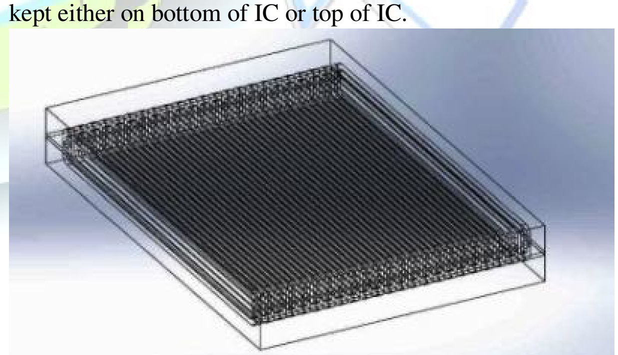

Fig 5. Wireframe of microchannel

When consider keeping system at the bottom of IC, some problems where found out. 1). the transferred heat to sink cannot be reject out as chip is attached to the board. Due to the lack of rejection of heat from the sink, there will be an increase in heat at the sink which can damage the system as well as IC chip. 2). The fluid flow through the microchannel is difficult so heat transfer from EC material cannot occur.

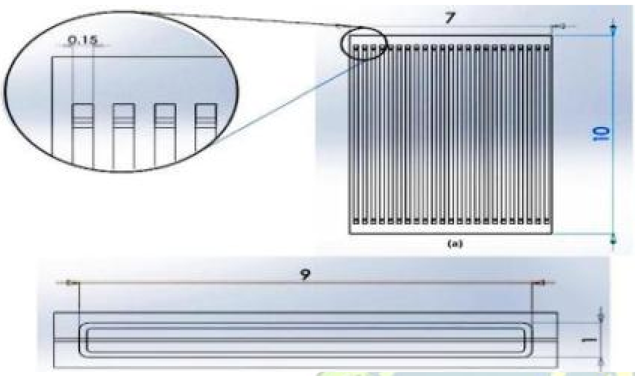


Fig 6. Microchannel Size and side view

When consider keeping system at the top of IC, it was found that the problems almost sorted out.1). As the system is on top there can be a direct heat transfer from sink to the atmosphere.so that a proper heat transfer is occur at the system.

2). When system is on top the fluid absorbs the heat from EC material. When heat is absorbed the fluid expands (density decreases) the cold fluid take place of hotter fluid as the colder fluid has larger density. So we can say that the flow can occur due to gravity.

## VII. CONCLUSION

A novel cooling system that work on electrocaloric effect was successfully designed. The materials used for the working of system was found to be P(VDF-TrFE-CFE) which is a terpolymer and the heat sink the material used is copper. Heat transfer fluid used is HT 55. The size of the system is found to be 1.6mm thickness 10 mm length and 7 mm width. A detail study on electrocaloric effect and EC material was conducted.

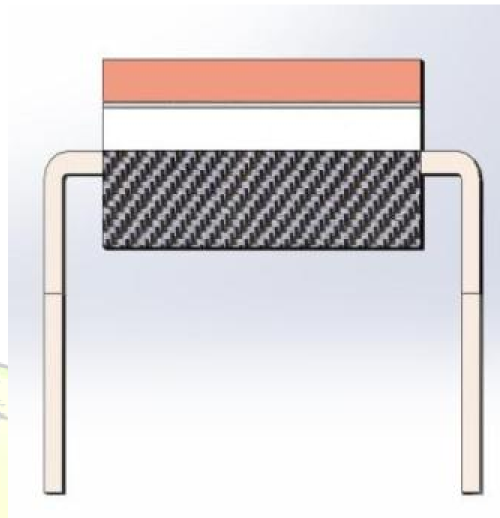

Fig 7. Preferred system arrangement on IC

A detail study on microchannel was also conducted and a mean size of the microchannel is taken for the passage of heat transfer fluid in the system. The system was made for a single integrated circuit which will produce approximately 0.93W of heat. It was also found out that 23 microchannels of 150 µm need to remove the heat produce by the integrated circuit.

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## REFERENCES

[1] A. Mischenko, Q. Zhang, J.F. Scott, R.W. Whatmore, and N.D. Mathur, “Giant electrocaloric effect in thin film $PbZr_{0.95}Ti_{0.05}O_3$,” Science 311, 1270-1271,2006

[2] Bret Neese,Baojin Chu, Sheng-Guo Lu, Yong Wang, E. Furman, Q. M. Zhang,“Large Electrocaloric Effect in Ferroelectric Polymers NearRoom Temperature”,*Science* **321**, 821 (2008);.

[3] Yanbing Jia and Y. Sungtaek Ju, “A solid-state refrigerator based on the electrocaloric effect,” Applied Physics Letters 100, 242901 (2012);.

[4] Dongzhi Guo, Jinsheng Gao, Ying-Ju Yu , Suresh Santhanam, Andrew Slippey, Gary K. Fedder "Design and modeling of a fluid-based micro-scale electrocaloric refrigeration system",International Journal of Heat and Mass Transfer 72 (2014) 559–564

[5] S.G. Lu, Q. M. Zhang, "Electrocaloric materials for solid-state refrigeration." Advanced Materials 21 (2009) 1-5.

[6] Christo Ananth, M.A.Fathima, M.Gnana Soundarya, M.L.Jothi Alphonsa Sundari, B.Gayathri, Praghash.K, "Fully Automatic Vehicle for Multipurpose Applications", International Journal Of Advanced Research in Biology, Engineering, Science and Technology (IJARBEST), Volume 1,Special Issue 2 - November 2015, pp.8-12.

[7] Donald. A. Neamen, "Electronic circuits analysis and design, Second edition".

[8] Bret Neese, S. G. Lu, Baojin Chu, and Q. M. Zhang,"Electrocaloric effect of the relaxor ferroelectric poly(vinylidene fluoridetrifluoroethylene-chlorofluoroethylene) terpolymer", Applied Physics Letters 94, 042910 (2009).

[9] Yang Bai, Guang-Ping Zheng , Kai Ding , Lijie Qiao, San-Qiang Shi and Dong Guo "The giant electrocaloric effect and high effective cooling power near room temperature for $BaTiO_3$ thick film", Journal of applied physics, **110**, 094103 (2011).

[10] Brigita Rožič, Marija Kosec, Hana Uršič, Janez Holc, Barbara Malič"Influence of the critical point on the electrocaloric response of relaxor ferroelectrics",Journal of Applied Physics. 110, 064118 (2011).

[11] Seri Lee" How to select a heat sink", www.aavid.com/sites/default/files/technical/papers/how-to-select-heatsink.pdf.

[12] R. Radebaugh, "Microscale heat transfer at low temperatures." Microscale Heat Transfer -Fundamentals and Applications, 2005, Springer, Berlin.

[13] Mark. E. Steinke and Satish. G. Kandlikar" Review of single phase heat transfer enhancement techniques for application in microchannels, minichannels and microdevices", Heat and Technology, Vol. 22, n. 2, 2004.

http://www.ulet.co.kr/product/Vacuum%20Fluids/heat/galden.html