International Journal of Computer Communication and Information System (IJCCIS) – Vol2. No1.   ISSN: 0976–1349 July – Dec 2010

A New Concept of Energy Recovery and Cooling Solution for Integrated Circuit Heat Using Thermoelectric Technology

P.Arunkumar[1], P.Iswarya[2], S.Supraja[3], P.RajaRajan[4] and G.Balaji[5]

[1,2,3,5]Department of Electronics and Communication Engineering,
[3]Department of Physics,
Angel College of Engineering and Technology,
Tirupur, TamilNadu, India.
[1]email: mps.arunkumar@ymail.com

***Abstract*--Waste heat from electronic components in information**

trivial. E

Circuits(IC's) in computers, servers and telecommunication equipment dissipate more amount of total energy as heat energy to the environment. Additionally, coolers have to be used in large amount to dissipate the heat from those equipments. Companies often spend large sums for cooling network servers, but we have found a way to cut those costs by using computer-generated heat to produce electricity. Energy recovered from the waste heat of IC's might be utilized for providing backup electricity in an emergency situation or providing electricity to drive electrical components. Thermoelectric generators are solid-state energy converters that combine thermal and electrical properties to convert heat into electricity or electrical power directly into cooling. Effective energy recovery may improve energy efficiencies and also life of IC and the equipment. This paper demonstrates the performance of a thermoelectric energy recovery module (TERM) in extracting the waste from electronics devices and their corresponding output was plotted and compared with ideal module.

***Index Terms*—Computer Generated Heat, Green Energy, Thermoelectric Energy Generator (TEG), Thin Film Thermoelectric.**

I. INTRODUCTION

Power is a valuable commodity, especially in mobile or embedded environments, and in server farms. In microprocessors, power is mostly dissipated as heat energy. This conversion to heat energy is a function of the size of the wires and transistors, and the operating frequency of the processor. As transistors get smaller, the depletion region gets smaller and current leaks through the transistor even when it is off. This leakage produces additional heat, and wastes additional power. Heat can also cause materials to expand, which can alter the electrical characteristics of the tiny transistors and wires. Many small microcontrollers don't need to worry about heat because they generate so little, but larger modern general purpose processors typically need to be accompanied by heat sinks and fans to help cool the processor. If a processor is running too hot, typically it can be slowed down to a lower clock rate to help prevent heat buildup.

energy converters that combine thermal, electrical, and typically, also semiconductor properties to convert heat into electricity or electrical power directly into cooling. Thermoelectric effect includes Seebeck effect, Peltier effect and Thomson effect; it also accompanies with other effects: Joulean effect and Fourier effect, etc [1]. With the development of society, and people's increasing consciousness of environmental protection and energy-saving, as well as the pressure caused by international energy crisis, to find new green energy sources has become a research hotspot, which includes the technology research and application of conversion various waste heat into electric energy by TEG [2]. Thermoelectricity in general is of strong scientific and technological interest due to its application possibilities ranging from clean energy to photon sensing devices. Recent developments in theoretical studies on the thermoelectric effects, as well as the newly discovered thermoelectric materials provide new opportunities for wide applications. Thermoelectric generation technology has been widely used in aerospace, defense, medical, scientific, and technological fields [3-4].

This paper aims at demonstrating the performance of a proposed TERM to generate electrical power from the waste heat of a computer processor and other IC's in it. This paper shows an experimental setup and then discusses thermal and power generating performances of the TERM at various source heat flows. The paper also discusses the results of an experimental parametric study to explore load resistance effects to the TERM performance.

II. RELATED WORK

Research activities in energy recovery from waste heat have considerably increased since the 1990s although there were many historical applications of TEGs using heating systems. There are recently reported researches such as thermoelectric power generation from CPU waste heat [5-7], Si-Ge based TEGs applied to gasoline engine vehicles [5], bismuth telluride based TEGs applied to diesel engines [9], thermoelectric power generation systems applied to generate the electricity from municipal waste heat [10], a thermoelectric power generator using solar heating [11], etc. Waste heat from electronic components may provide lower temperature condition for the TEG hot side than other resources such as automotive waste heat do. The additional thermal resistance due to the TEG may increase the junction temperature of the electronic component. Hence, the energy recovery system should be carefully designed.

In TEG system design, it is crucial to accurately predict the performance of TEG according to thermal conditions since the thermoelectric properties vary with the operating temperatures [14, 15].

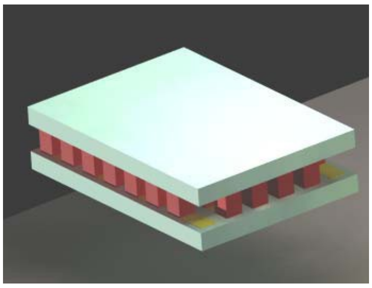

Figure 1. A thermoelectric module is made up of a number of thermocouples connected in series. In this representation a unified header combines all the thermocouples together.

Recently reported nanostructured thermoelectric materials [12-15] may provide higher figure of merits than classical thermoelectric materials but the actual application of nanostructured thermoelectric materials doesn't seem to be very practical yet due to difficulties in fabrication and packaging. Hence, a system level investigation may provide an alternative solution to improve energy recovery performance. However, only a few studies have been reported regarding the system level performances of the thermoelectric energy generation modules from the waste heat of electronic components. There is no reported study experimentally exploring the system level performance of the thermoelectric energy generation module from the waste heat of Integrated Circuits. Hence, this work reports measurement results of the system level performance of the thermoelectric energy recovery module (TERM) proposed to recover the energy from PA transistor waste heat.

III. SYSTEM ARCHITECTURE AND DESIGN

A. System Arrangement

The main heat source of the project is the processor in the computer. The processor with the fan is replaced with thermoelectric material. As shown in Fig.2, On the top of the processor a heat spreader made up of Copper is placed. This act as a heat spreader and a quick absorber of heat, since copper is a good conductor of heat. The heat absorbed by this copper is given to the TEG which kept is series arrangement. The thin film TEG absorbs the heat and the transition of heat from the hot junction to the cold region produces a voltage across the terminals. The cold junction has to reject the heat at a faster rate, so that the difference of temperature can exits across the terminals of TEG. An aluminum heat sink acts a medium for the cold junction to reject the heat to the atmosphere.

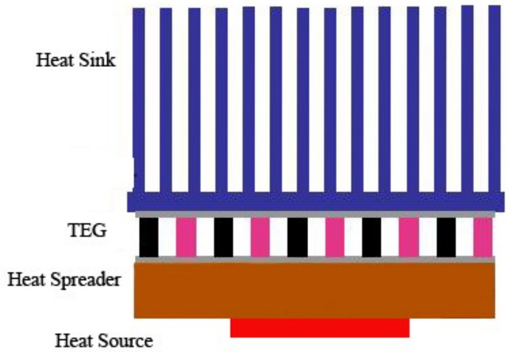

Figure 2. TERM with a heat source

B. Thin Film Thermoelectric Technology

The thin file thermoelectric cell is shown in Fig.1. The most basic representation of thermoelectric device performance is its load line. A load line represents the Q_{pumped} and ΔT conditions possible for a given TEC drive current. At the maximum drive current for the module, the load line is generated from two key parameters:

- maximum power the device can pump, Q_{max}
- maximum temperature difference that the device can sustain between its top and bottom plates, ΔT_{max}.

ΔT_{max} is measured when no heat is flowing through the device (zero Q condition) and can be theoretically obtained from:

$$\Delta T_{max} = \frac{a^2 T_c^2}{2K\rho} = \frac{a^2 T_c^2}{2KR} \qquad (1)$$

where, α is the Seebeck coefficient,
k is the thermal conductivity,
ρ is the electrical resistivity,
T_c is the cold junction temperature,
K is the thermal conductance

On the other hand, Q_{max} represents the maximum amount of heat that can be pumped as the temperature difference between the top and bottom plates goes to zero and is shown in (2).

$$Q_{max} = \frac{A\alpha^2 T_c^2}{2\rho L} = \frac{\alpha^2 T_c^2}{2R} \qquad (2)$$

where A is the area of the device and L is the length (or thickness) of the thermoelectric material.

Whereas ΔT_{max} is not theoretically expected to change as material thickness changes (although it does somewhat because of other losses incurred by making the device thinner), Q_{max} is inversely proportional to the thickness (L), and therefore increases substantially as the material is made thinner. This small value for L allows exceptionally resistances. A higher power densities than conventional thermoelectric modules.

TABLE 1
ELECTRICAL PARAMETERS OF THE THERMOELECTRIC MATERIAL

Characteristics	Units	Targets
X (width)	mm	5.0
Y (length)	mm	4.0
H (height)	mm	0.7
Area	cm^2	0.200
Resistance	Ω	0.315

C. *Power Generation*

A thermoelectric device is an energy conversion system that converts thermal energy to electrical energy. A device of this type is commonly referred to as a thermoelectric generator (TEG). The characteristic of the material used is shown in Table.1. The fundamental physics of this type of energy conversion can be found in the literature from multiple sources. To summarize the literature in one sentence, the temperature difference (ΔT) between the hot (T_h) and cold (T_c) sources leads to a difference in the Fermi energy (ΔE_F) across the thermoelectric material yielding a potential difference, which drives a current. This paper addresses the unique performance and design aspects of using thin film thermoelectric materials to produce high performance TEGs for extracting maximum amount of heat.

A thermoelectric generator convert's heat (Q) into electrical power (P) with efficiency η.

$$P = \eta Q \qquad (3)$$

Larger devices that utilize more heat Q will produce more power P. Similarly, the use of twice as many power converters will naturally produce twice the power given they can capture twice the heat. Without a specific constraint on heat flux and system geometry, it is convenient to focus on power per unit area (P/A) produced and heat flux density (Q/A) rather than absolute power and heat consumed (4). This is particularly convenient for thermoelectric power generation because the systems are so easily scalable: a large system can simply be an array of smaller systems.

$$\frac{P}{A} = \eta \frac{Q}{A} \qquad (4)$$

D. The Importance of System Thermal Performance Optimization

The maximum efficiency of a thermoelectric converter depends heavily on the temperature difference ΔT across the device. The efficiency of a thermoelectric generator, like all heat engines, cannot be greater than the Carnot efficiency defined as $\eta_c = \Delta T/T_h$,

Here η_r is known as the reduced efficiency, which is less than unity and related to the thermoelectric figure of merit, ZT. Because η_r/T_h is fairly constant with respect to temperature variations, particularly at small ΔT, the efficiency of a TEG will increase linearly with temperature difference. For maximum Power/Area for a given TEG, the following three conditions should be maximized:

- input heat/area, Q/A
- temperature difference, ΔT and
- thermoelectric figure of merit, ZT.

As a consequence, a very important design parameter is the module packing fraction, f, which is a ratio of the total active area of the thermoelectric material (A) in the module relative to the total module area (A_{module}).

$$f = \frac{A}{A_{module}} \qquad (6)$$

The heat/area, heat flux, absorbed into the thermoelectric generator by means of conduction heat transfer due to the temperature difference can be expressed using the material thickness, L and thermoelectric material packing fraction f as:

$$\frac{Q}{A_{module}} = k_{eff} \Delta T \frac{f}{L} \qquad (7)$$

where k_{eff}, is the effective thermal conductivity of the thermoelectric material.

Thus, if ΔT and f are kept constant, then the heat flux Q/A (and therefore the output power density P/A) can in principle be made arbitrarily large by decreasing the thermoelectric material thickness, L. Of course, in practice, ΔT is difficult to maintain as L decreases and for maximum power the thermal resistances of the heat source and sink must be carefully considered. If either the heat source or heat sink has a large thermal resistance, the heat flux supplied to the thermoelectric generator will be reduced. Heat exchangers used as sinks and sources are often characterized by a thermal resistance Θ which is defined as the temperature difference divided by the amount of heat flow ($\Delta T/Q$). Or, the temperature drop across the heat exchanger (H_x) is proportional to the heat supplied,

$$\Delta T_{Hx} = \Theta_{Hx} Q \qquad (8)$$

where ΔT_{supply} is the temperature difference between a source and a sink (for example: a hot and cold bath), ΘTE is the thermal resistance of the thermoelectric device and Θ_{Hx} is the combined thermal resistance of the hot and cold side heat exchangers.

From this thermal circuit, one can show that the temperature difference across the thermoelectric device and heat flow in the circuit are given by

$$\Delta T_{TE} = \Delta T_{supply} \frac{\Theta_{TE}}{\Theta_{Hx} + \Theta_{TE}} \qquad (9)$$

From this analysis the highest power is achieved when the thermal resistance of the heat exchanger is minimized and the combined resistance is optimized. Heat exchangers also scale with size: larger heat exchangers carry more heat and have lower thermal resistance. Thus the product of thermal resistance times the area, ΘA, is relatively independent of the size of a heat exchanger. A typical ΘA value for well designed air-cooled heat sinks is 5 Kcm^2/W. For liquid-cooled heat exchangers a typical value is 0.5 Kcm^2/W. The ΘA value, sometimes called the thermal impedance, for a thermoelectric is derived by rearranging (7) as,

$$\Theta_{TE} A = \frac{\Delta T_{TE}}{Q/A} = \frac{L}{\kappa_{eff} f} \qquad (11)$$

E. Basic Equations Governing TEG Performance

A thermoelectric generator produces electrical power because of the Seebeck effect. The Seebeck voltage (V_{oc}, measured under open circuit conditions) produced is directly proportional to the temperature difference.

$$V_{oc} = S\Delta T \qquad (12)$$

where S represents the device Seebeck coefficient. During operation of the TEG, the output voltage is reduced by the Ohmic voltage drop due to the internal resistance of the device. Consequently, the voltage at maximum power is about half that of the open circuit voltage VOC (V_{oc}=SΔT≈2V_{max}) and the maximum power changes with temperature difference as ΔT^2.

$$P = \frac{V_{max}^2}{R} = \frac{V_{oc}^2}{4R} = \frac{S^2 \Delta T^2}{4R} \qquad (13)$$

The efficiency of a TEG is governed by the properties of the thermoelectric materials and the temperature drop across them. The temperature difference, ΔT between the hot side (T_h) and the cold side (T_c) sets the upper limit of efficiency through the Carnot efficiency $\eta_c = \Delta T/T_h$. The thermoelectric material governs how close the efficiency can be to Carnot primarily through the thermoelectric figure of merit, Z, defined as

$$z = \frac{\alpha^2}{\kappa\rho}$$

where the relevant materials properties are the Seebeck coefficient α, the thermal conductivity k, and electrical resistivity ρ, all of which vary with temperature.

If the efficiency and ΔT are measured then an effective Z can be calculated. Assuming Z remains relatively constant in temperature, this equation can then be used to calculate efficiency for any given ΔT.

$$P = \frac{V_{oc} \cdot I_{sc}}{4} = \frac{V_{oc}^2}{4R} = \frac{(S.\Delta T)^2}{4R} \qquad (14)$$

31

$$V_{oc} = I_{sc}.R = S.\Delta T \qquad (15)$$

IV. RESULT AND DISCUSSION

Thermoelectric(4x4) devices (16 PN couples) have been characterized for power generation with temperature differences up to 200K while T_c was maintained constant at 30ºC (303K). The open circuit voltage, short circuit current, the AC resistance, and performance driving a load are measured for a given temperature difference. These devices show consistently high power output per unit area, as is expected due to the short thermoelectric element thickness, L. Efficiency is directly proportional to the temperature difference (ΔT) across the module. To achieve the highest operating efficiency possible, the distance between heat source and module should be close as possible, to maximize the temperature across the module.

Any heat flowing through the underfill decreases efficiency, and should be minimized. So, the total heat available for power conversion is increased when the thermoelectric thermal conductance is increased. Since the thermal conductivity (kTE) is an intrinsic material property, not a design parameter, the thermoelectric area to length ratio (ATE/LTE) is the primary device design parameter that can be manipulated to control Q.

TABLE 2
ELECTRICAL PARAMETERS OF THE THERMOELECTRIC MATERIAL

Voc(mV)	R(mΩ)	ΔT(K)
135	151	36
381	163	94
504	156	132
619	148	189

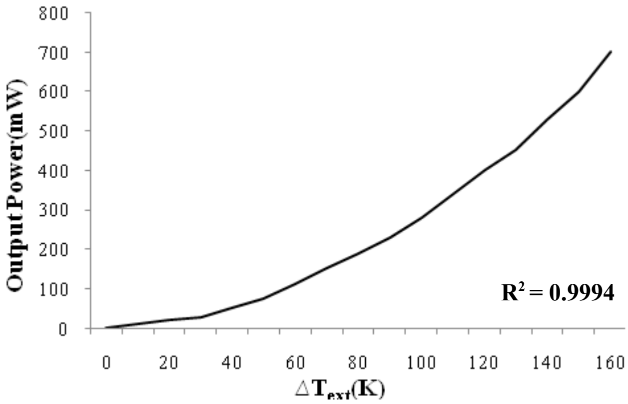

Figure 3. Output power as a function of external temperature difference (ΔT) across the device.

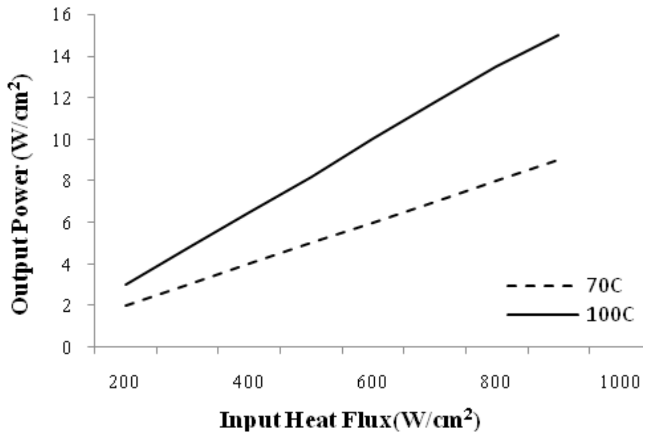

Figure 4. Output Power vs. Input Heat Flux

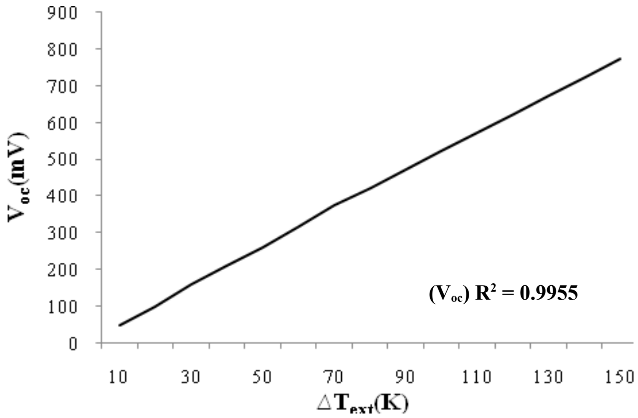

Figure 5. V_{oc} as a function of the ΔT_{ext}

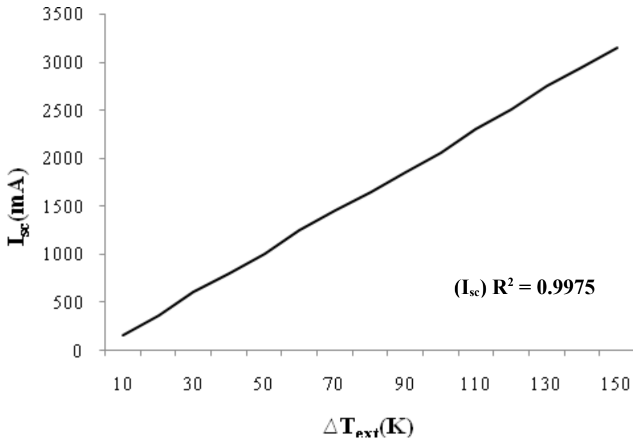

Figure 6. Isc as a function of the ΔText

In (14) and (15), R is the device electrical resistance and S is the device Seebeck coefficient. The correlation coefficient (R2) in the lower right hand side of Fig.3 indicates that 99.94% of the variation in the data is accounted for in the parabolic fit as expected from (14).

The parameters used to calculate the output power are, as indicated in (14), Voc and Isc. Voc and Isc are shown in Fig.5 and Fig. 6 as a function of ΔT_{ext}. Voc measurements are represented by blue squares. Linear

resistance and electrical parameters at the increasing temperature difference.

Fig. 4 shows the impact of packing fraction on the input heat flux. It is clear from these figures that higher output powers are possible if the module active area packing fraction is increased, which will increase the input heat flux.

V. CONCLUSION

The prototype of a thermoelectric energy recovery module (TERM) was generated. The TERM is aimed at converting the waste heat from processor into electrical energy. Results demonstrated an obvious fact that the greater heat energy into the TERM, the better generation performance. Generated power profiles with respect to source heat flows appeared to be parabolic. This result is mainly due to the fact that the generated power varies quadratically with the temperature difference across TEG's hot and cold sides. The junction temperature was seen to almost linearly vary with the source heat flow. With this project it is possible to eliminate the need of Coolers for Servers and also additional energy required to run the coolers. The waste heat is converted into useful power and also from the generated power it is possible to un any one of the module in the computer. The same concept when applied to large database servers will bring enormous amount of energy saving to the world. Also, the companies looking for the Cooler Server can also be satisfied with considerable cost.

REFERENCES

[1] Song Rui-yin, "Study on micro(small) thermoelectric generation device with heat and sink source", *Hangzhou: The College of Mechanical and Energy Engineering Zhejiang University*, pp. 20-23, 2005.

[2] Luan Wei-ling, TU Shan-dong, "Research Progress of Thermoelectric Technology", *Journal of Chinese Science Bulletin*, vol. 49, no.11, pp.1011-1019, 2004.

[3] S.B.Riffat, Xiaoli Ma, "Thermoelectrics: a review of present and potential applications", *Journal of Applied Thermal Engineering*, vol.23, pp.913-935, 2003.

[4] D.M. Rowe (ed.), "CRC Handbook of Thermoelectrics", *CRC, Boca Raton, FL*, 1995.

[5] G.L. Solbrekken, K.Yazawa, A. Bar-Cohen, "Heat Driven Cooling of Portable Electronics Using Thermoelectric Technology", IEEE Trans. Adv. Packaging, vol. 31, no. 2, pp. 429-437, 2008.

[6] Suski and D. Edward, "Method and apparatus for recovering power from semiconductor circuit using thermoelectric device," U.S. Patent 5, 419, 780, 1995.

[7] K.Yazawa, G.L. Solbrekken and A. Bar-Cohen, "Thermoelectric Powered Convective Cooling of Microprocessors," *IEEE Trans. Adv. Packaging*, vol. 28, no. 2,

the device Seebeck coefficient (S). Table 2 shows the

[8] K.Ikoma, M.Munekiyo, K.Furuya et al., "Thermoelectric Module and Generator for Gasoline Engine Vehicles", *Proc. 17th*

Internat. Conf. on Thermoelectrics, Nagoya, Japan, pp. 464-467, 1998.

[9] J.G. Haidar, J.I. Ghojel, "Waste Heat Recovery from the Exhaust of Low-Power Diesel Engine Using Thermoelectric Generators", *Proc. 20th Internat. Conf. on Thermoelectrics*, Beijing, China, pp. 413-417, 2001.

[10] T. Kajikawa, "Status and Future Prospects on the Development of Thermoelectric Power Generation Systems Utilizing Combustion Heat from Municipal Solid Waste", *Proc. 16th Internat. Conf. on Thermoelectrics*, Dresden, Germany, pp. 28-36, 1997.

[11] S. Maneewan, J. Khedari, B. Zeghmati et al., "Experimental Investigation on Generated Power of Thermoelectric Roof Solar Collector*", Proc. 22nd Internat. Conf. on Thermoelectrics*, Montpellier, France, pp. 574-577, 2003.

[12] T.C. Harman, P.J. Taylor, M.P. Walsh et al., "Quantum Dot Superlattice Thermoelectric Materials and Devices", *Science*, vol. 297, no. 5590 , pp. 2229-2232, 2002.

[13] A.I. Hochbaum, R. Chen, R.D. Delgado et al., "Enhanced Thermoelectric Performance of Rough Silicon Nanowires", *Nature*, vol. 451, no. 7175, pp. 163- 167, 2008.

[14] K.F. Hsu, S. Loo, F. Guo et al., "Cubic AgPbmSbTe2+m: Bulk Thermoelectric Materials with High Figure of Merit", *Science*, vol. 303, no. 5659, pp. 818-821, 2004

[15] R. Venkatasubramanian, E. Siivola, T. Colpitts et al., "Thin-Film Thermoelectric Devices with High Room- Temperature Figures of Merit", *Nature,* vol. 413, no. 6856 , pp. 597-602, 2001.

[16] I. Boukai, Y. Bunimovich, J. Tahir-Kheli et al., "Silicon Nanowires as Efficient Thermoelectric Materials", *Nature*, vol. 451, no. 7175, pp. 168-171, 2008.