Thermionic Emission based Processor Heat Utilization

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ABSTRACT
The idea is to convert the heat generated in computer processors to electrical energy and increase the battery back-up time of the system. A cathode of low work function will closely surround the processor. An anode will be kept closely to cathode. A unit comprising of a rechargeable Li-ion battery will be connected in series with anode. A switching circuit, with one path to the computer power circuitry and the other to the rechargeable battery unit will be developed. Once the processor starts functioning, heat will be generated and it will force the cathode to emit electrons. The electrons will be collected by anode and then deposited into the rechargeable battery and electrical energy can be stored. When the battery back-up time goes beyond a certain level (5-10% of max.), the switching circuit will enable the rechargeable battery unit and it will deliver power to the notebook and back-up time can be increased.

Keywords
Processor heat, work function, electron emission.

1. INTRODUCTION
Modern processors have become victims of more power consumption and power has emerged as a major design constraint. Power consumption can be attributed to two major components i.e. dynamic power and static power. Since frequency of operation for processors have increased, dynamic power has increased. Shrinking of transistor size to nanometer scale has resulted in escalation of static power. Absence of a system that can convert the heat generated in processors into useful electrical energy has resulted in loss of reusable energy. Power dissipation range of some Intel desktop microprocessors is found to be 100-150 Watt [4]. This has led Intel to set a limit at 100 Watt [7].

Here we report an experiment carried out at ITER to measure the temperature range reached by an Intel Core 2 Duo (2.2 GHz) microprocessor. LM 35 temperature sensor was used along with 8051 microcontroller for interfacing and 0804 ADC chip. Only a part of the experiment is produced where the processor temperature was remarkably high. At this temperature range, the system was also hanged.
The temperature (all in ºC) attained was:

Table 1. Data from experiment carried out on Core 2 Duo (2.2GHz) Lenovo processor

Processor Temp	Main Board Temp	Core2 Temp	Core1 Temp
63	67	97	100
63	68	97	100
64	68	98	98
62	68	100	97
63	68	98	100
62	68	97	100
62	68	100	97
62	68	100	97

2. PRINCIPLE
One of the possible methods to utilize this heat is through thermionic emission. We place a rectangular cathode closer to the processor, separated by only a slim air gap. An anode surrounds the cathode. Wires are connected to the anode in symmetric positions and directed to a rechargeable battery. Heat produced by processor excites electrons of cathode. Once electrons are emitted, they will be received by anode and then passed to rechargeable batteries connected in series. These batteries can now be used as secondary power source for the computer. In Fig.1 the proposed system diagram is shown.

The vacuum box is provided to ascertain no loss of electrons which would otherwise have been lost or deflected. Cathode surface is teeth-shaped or contains regular surface aberrations to facilitate easier and more emission of electrons. Also, cathode is connected to negative terminal of a voltage source V in series with a resistance R. When cathode will emit electrons, it will develop a positive potential and further emission of electrons will be difficult. To counter this effect, a negative potential is provided that will compensate loss of electrons from cathode

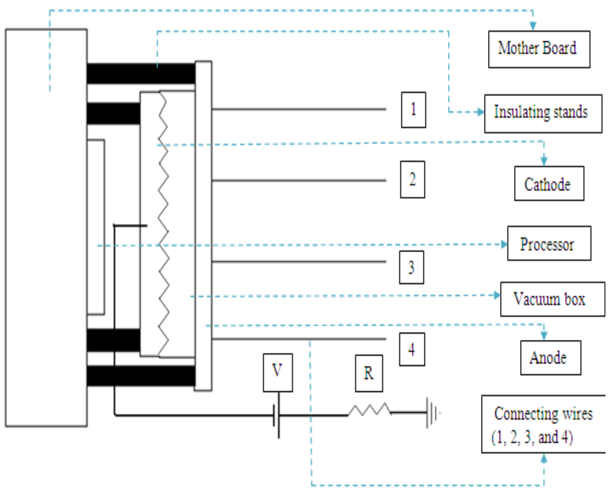

Fig 1: proposed system diagram.

3. ANALYSIS

3.1 No. of Ejected Electrons and Current Density

We assume the following parameters along with uniform heat distribution on cathode surface: A=area of cathode surface, r=effective radius of one cathode atom/molecule, m=no of electrons emitted by one cathode atom/molecule, N=total no. of electrons emitted within a time interval 't'. Hence, effective no. of atoms/molecules on

Cathode surface$=\left(\frac{A}{\Pi r^2}\right)$. **So,** $N=\left(\frac{A}{\Pi r^2}\right)m.$

Amount of charge emitted by N no. of electrons=Ne. Current associated with this charge is **I=Ne/t.**

Current density $J=I/A=\frac{Ne}{At}=\frac{me}{\Pi r^2 t}$.

3.2 Velocity of emitted electron

Let w = heat produced by the processor, ηw = heat received by the emitting side of cathode (To quantify the loss when heat flows from processor to cathode, we introduce the factor η, $0 < \eta < 1$.), Φ = thermionic work function of cathode, σ = surface losses in the cathode, N = no. of electrons emitted, m= mass of one electron and v = velocity of ejected electrons. Energy received by one electron in cathode = ηw/N. Applying conservation of energy for one electron and assuming uniform heat distribution on cathode surface,

$$\frac{\eta w}{N}=\frac{1}{2}mv^2+\Phi+\sigma. \textbf{ Hence, } v=\sqrt{\left[\frac{2\left(\frac{\eta w}{N}-\Phi-\sigma\right)}{m}\right]}.$$

3.3 Heat Equation

To determine the amount of heat flowing from processor to cathode end, we turn to heat equation. The heat flow here can be assumed one-dimensional. Solving the one dimensional heat equation i.e. $\frac{\partial u}{\partial t}=c^2\frac{\partial^2 u}{\partial x^2}$, temperature at required points within the air gap and cathode material can be found out. The solution to heat equation by Fourier Integral and Transforms is:

$$u(x,t)=\frac{1}{2c\sqrt{(\Pi t)}}\int_{-\infty}^{\infty}f(v)e^{-(x-v)^2/4ct^2}\,dv.$$

x is the coordinate from the surface of the processor to the cathode. f(x) is initial condition i.e. u (x, 0)=f(x). f(x) is an experimental parameter that can be determined by placing temperature sensors at the fixed points i.e. top surface of processor, mean air gap temperature, lower surface of cathode, upper surface of cathode. We assign the above points the following dimensions to make the analysis easier i.e. top surface of processor = x1, midpoint of air gap = x2, lower surface of cathode = x3, upper surface of cathode = x4.

3.4 Heat Flow from Processor to Cathode

Region between processor and cathode is filled with air gap, so heat flows by convection i.e. $Q=hA\,[T1-T2]$ with the parameters defined as h= convective heat transfer co-efficient of air, A=area of cathode surface, T1= temperature of top surface of processor = u(x1, t), T2=mean temperature of air gap = u(x2, t), Q=rate of conductive heat transfer (energy per unit time).

T1 and T2 can be calculated by solving heat equation. Since, u(x1, 0) = f(x1), u(x2, 0) = f(x2) and f(x) can be found out by placing temperature sensors at x1 and x2. It can be substituted back to heat equation. Now T1 and T2 can be put in to equation for convection and convective heat can be calculated.

3.5 Heat Flow in Cathode

Heat flow in cathode takes place by conduction i.e. $Q=-kA\left(\frac{dT}{dx}\right)$ with the parameters understood as k = thermal conductivity of cathode material, A = surface area of cathode,

$$\left(\frac{dT}{dx}\right)=-\left(\frac{T3-T4}{x3-x4}\right) = \textbf{temperature gradient,}$$

T3 = temperature of lower surface of cathode = u(x3, t),
T4 = temperature of upper surface of cathode =u(x4, t),
dx= x4-x3= thickness of cathode material and
Q= rate of conductive heat transfer (energy per unit time).

k is an experimental parameter that depends on property of cathode. u(x3, 0) = f(x3), u(x4, 0) = f (x4) and f(x) can be found out with the help of temperature sensors at x3 and x4. It can be substituted back to heat equation and T3 and T4 can be calculated. From conduction equation, rate of conductive heat flow can be determined.

3.6 Efficiency

Assuming W1=heat produced on the surface of the processor, W2=heat on lower (receiving) surface of cathode, W3=heat on upper (emitting) surface of the cathode,

$$\textbf{Efficiency} = \eta = \frac{W1}{W3} = \frac{W1/t}{W2/t} = \frac{Q1}{Q3}$$

Where Q1 and Q3 define the rate of heat flow at the corresponding points. Q1, Q2 and Q3 are obtained from equations for convection and conduction.

3.7 Penetration depth

As electrons hit the anode, they give their energy to anode lattice and velocity reduces. An ejected beam of λ electrons/cm² can be distributed approximately by Gaussian formula

$$N(x) = \frac{\lambda}{(\Delta Rp)\sqrt{(2\Pi)}} e^{-\frac{1}{2}[(x-Rp)/\Delta Rp]^2}$$

where Rp=penetration depth, ΔRp= straggle measures the half width of the distribution at $e^{(-1/2)}$ of peak, N(x)=electron concentration.

4. DIMENSIONS

The standard processor dimensions for Intel notebook processors is 31 mm* 35mm [5]. Dimensions for cathode, anode and insulating stands can be proposed in the following way.

4.1 Cathode

It can be set to 40 mm x 40 mm x 1mm. We have chosen it to be a square to take advantage of uniform heat distribution. 1 mm is a tentative thickness keeping in view that maximum heat is absorbed within cathode for heating up from its lower surface and also that sufficient no. of electrons are ejected from upper surface of cathode.

4.2 Anode

It can be set to 45mm x 45mm x 1mm. The extra 5mm length and breadth than cathode is provided for a proper coverage so that minimum no. of emitted electrons is lost. 1 mm is also a tentative thickness here. Length of half of each side of the anode = 45/2 = 22.5 mm. Distance from centre of anode to one of its corner = 22.5 x $\sqrt{2}$ = 31.82 mm. We choose midpoints of the lines joining the centre of anode to corner points as a, b, c, d to connect wires to carry electrons to secondary battery. Distance of any of the points a, b, c, d to their corner points = 31.82 /2 = 15.91 mm. Four wires are provided to avoid electron traffic jam.

4.3 Insulating stands

Two insulating stands are provided at two corners of cathode to support it at a fixed distance closer to processor. We could have provided four stands at four corners for better support, but our concern is to project maximum effective area of cathode towards processor so that maximum heat is absorbed into cathode. Height of stand= Height of processor up motherboard + thickness of air gap between processor and cathode=4mm+2mm=6mm. So, dimension of insulating stand for cathode= 3mm × 3mm × 6mm.

Similarly we choose only two insulating stands instead of four to support anode. Length and breadth are 3mm×3mm. Height = Height of processor from motherboard + thickness of air gap between processor and cathode + cathode thickness + thickness of vacuum box = 4mm +2mm + 2mm + 2mm = 10mm

5. SWITCHING CIRCUITRY:

A circuit that engage both main battery of the computer and the proposed secondary battery that may given in the following Fig 2:

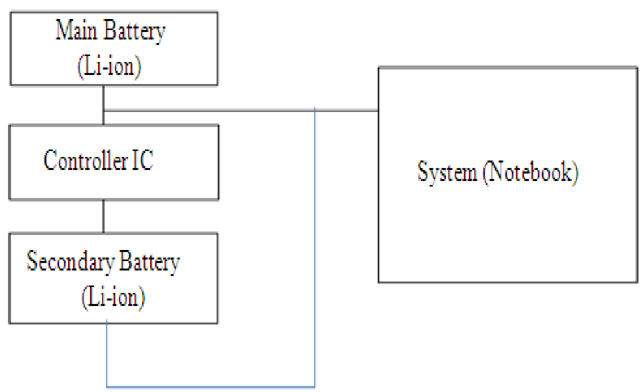

Fig 2: proposed secondary battery for the system.

The main battery here is the one supplying power to notebook. Secondary battery comprises of 4 cells of Li-ion rechargeable battery and provides 4×3.7 = 14.6 Volt required for notebook to function. Controller IC is able to communicate with both main battery and secondary battery. As soon as the controller IC will sense the main battery going out of action (say 5% of maximum energy) it will immediately throw secondary battery into use. The secondary battery will now start delivering power through the path shown above in blue.

6. CHALLENGE

To emit sufficient electrons at the temperature range attained by processors, we need to have a cathode with work function at least 0.1eV. Presently no material is available that has work function as low as required (0.1eV). The material In0.3Ga0.7As coated with very thin layer of Cs and O [6] has been recently reported. Advancements in fields of composite material, meta-materials, nanotechnology can be expected to take it one step ahead.

7. ACKNOWLEDGMENTS

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