A new proposal of Peltier cooling for microprocessor

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ABSTRACT

The performance of microprocessor (CPU) is improving in the past 30 years, and it will be continued in this century. The electric power consumption of the CPU is increasing along the improving the performance of the CPU. Therefore, it is important to cool down the CPU. Heat power density is ~ 10 W/cm^2 in the present CPU, and its values is the same magnitude of the electric heater's. Peltier module (PM) was once used to cool down CPU in late 1990's to early 2000's. However, PM is not used as the common cooler in the present time. There are two reasons not to use the PM for cooling the CPU. One is its electric power consumption of the PM, and it is almost same as the CPU's itself. The other reason is dew drop. The power consumption of the CPU is changing every time by its job, and when its consumption is low, the dew drop was found inside the computer. The PM is operated as "Qmax operation" because the temperature difference between two sides of the PM is almost zero. Our proposal to use the short leg of Bismuth telluride alloy (BiTe). If we cut the leg to 1/5 of an usual PM, the value of "Qmax" is increased 50% and the electric power consumption of the PM is 1/5. This is one of the solution to cool down the CPU. BiTe is an usual material to make the PM, however we usually use the material of high thermal conductivity to spread the heat flux. Therefore, the material

of high thermal conductivity is better to use to spread heat flux, and silicon carbide is one of the candidates to make PM for CPU cooling.

INTORODUCTION

Microprocessor (CPU) is one of the most important electric devices in the present world. Because of many requirements, the performance of the CPU is improving quickly, and the number of transistors in one CPU is increasing, and the core frequency of the CPU is faster. Figure 1 shows the trend of the number of the transistors in one CPU and the core frequency [1].

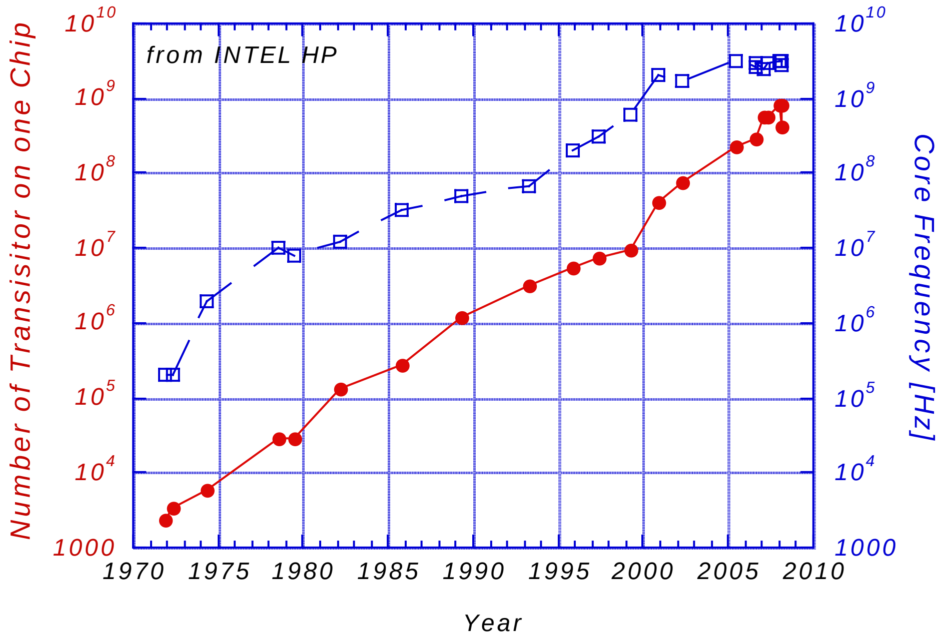

Figure 1 Trend of number of transistors in one chip and the core frequency.

CPUs are installed into almost all modern instruments, and these instruments are connected by internet. Fast communications between the instruments are needed, and the Internet traffic is increasing quickly. The Internet traffic will be forecasted to be 200 times larger until 2025 in Japan, and this forecast is same for all countries in the world. This means that we must construct many Internet data center (iDC) in which many computer servers are used, and the electric power consumption would be estimated to be half of the total electric power consumption in 2050. Actually, iDC consumes 5% of total electric power in Japan and 7% in USA now. The main reason of increase of iDC's power consumption is the increase of CPU's power consumption. Figure 2 shows the trend of the electric power consumption of one CPU chip [1].

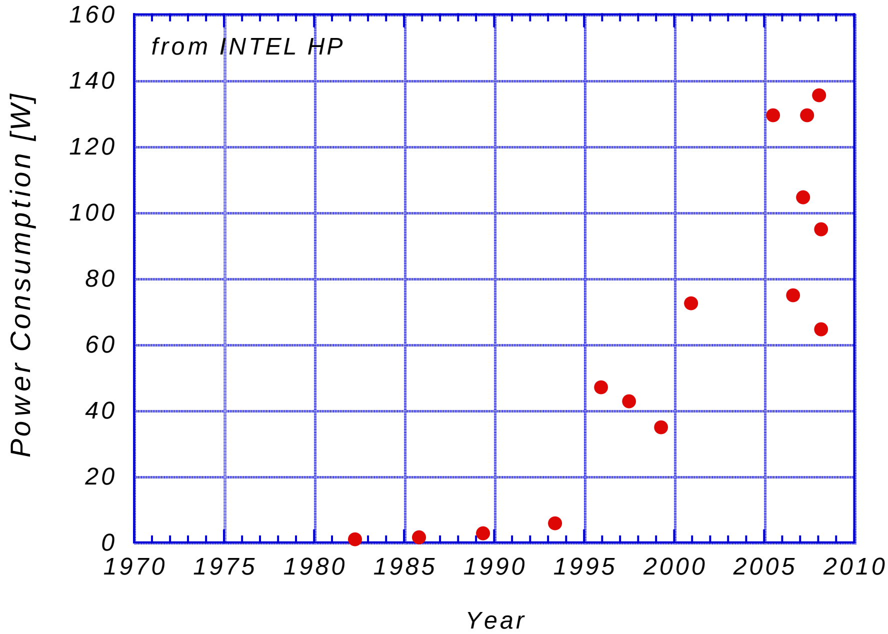

Figure 2 Trend of electric power consumption by one chip.

Therefore, there are two important problems, one is the reduction of electric power consumption, and the other is how to cool down the CPU chip. Here, we discuss the cooling problem. Heat generation density of electric power consumption of CPU is almost the same as the infrared electric heater in the present time. In order not to increase the operation temperature of CPU, the electric power consumption of the CPU is almost constant for the last four years because the size of chip is almost constant and we did not find effective cooling method for the CPU.

Cooling methods were changed along the electric power consumption in the past two decades. Fin was used for cooling in 1980's at first, and the system of fin and fan was used in early 1990's. Peltier module (PM) was used in the middle of 1990's but it is not used now. The cooling system is composed of heat pipe (HP) [2] fin and fan even for personal computer (PC) after 2000's, and the boiling cooling element [3] is used for high performance CPU now.

There were two reasons to abandon the PM. One is electric power consumption. The PM consumed almost same electric power of the CPU. It means that the electric power consumptions of PC and the server in iDC would be almost double. For example, the electric power consumption of the CPU is 100 [W], and the PM's is almost 70 [W] in order to transfer the heat flux of the CPU. The temperature difference of the hot side and the cold side of the PM is almost zero or 2 to 3 K because the transferred heat flux is high, and therefore the PM is in "Qmax operation" when the CPU's power consumption is high. Since he PM cannot absorb the heat flux, we should prepare a large fin and fan.

The electric power consumption of the CPU is changing every time because the processing of the CPU depends on the software and its job processes. When the CPU processes the streaming data, the electric power consumption is high. When the electric power consumption of the CPU is low, the dew drop was sometimes found inside the computer because the PM generate large temperature difference. It is dangerous for the computer.

Therefore, we can summarize the technological problems to use the PM for cooling of the CPU as below,

1) reduce electric power consumption
2) increase transfer heat flux (Qmax),
3) avoid dew drop or not to realize high temperature difference between two sides of the PM

If these conditions are realized at the same time, we will find a large market of the PM.

PROPOSAL

At first we must back to the reason to use the PM in 1990's. Since the PM cannot absorb heat flux and it can only transfer the heat flux, we need to use the instruments to absorb the heat flux, such as fin and fan. Therefore, the function of the PM should reduce the thermal resistance or be a heat spreader. See figure 3. When the power consumption of the CPU is high, we need to use a large fin. But we must find wide area to attach the large fin in order to solve this problem. Therefore, we must use the heat spreader. The function of the heat spreader keeps the same temperature of the contact surfaces of the fins at least. This requirement is given by

$$T_1 \leq T_2 \;\&\; T_3 \qquad (1)$$

Theoretically the temperature differences between T_1 and T_2, T_3 are zero, but actually T_1 is lower than T_2, T_3 slightly for effective cooling, and the temperature difference would be

2 to 3 K..

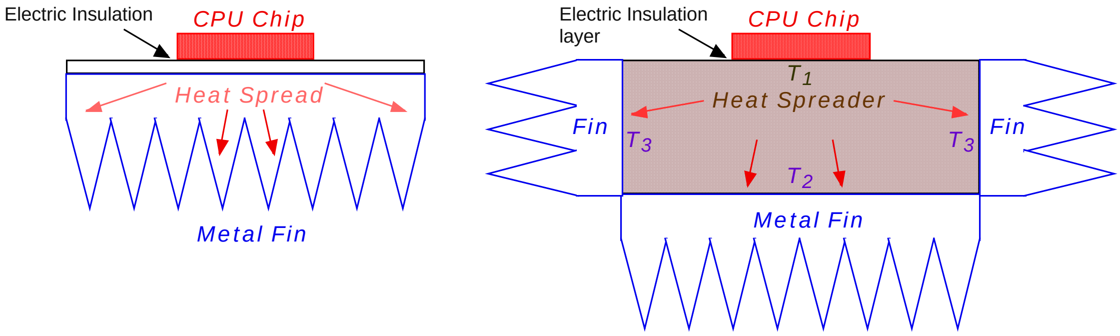

Figure 3 Small fin and Large fin for cooling the CPU.

One of the examples to use the PM in the present time is shown in Fig. 4 [4].

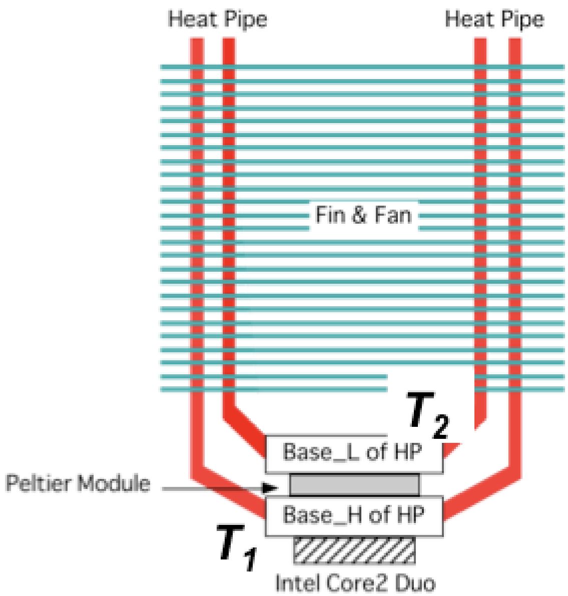

Figure 4 CPU(Core 2 Duo) and cooling system composed by PM, HP and Fin.

This cooling unit is selling in the present time (August, 2008) and made in USA. The system use PM, HP, and fin and fan. An usual PM is used, and it uses the BiTe alloy. The length of leg of BiTe is 1.5 mm, and if the heat load at the cold side is zero, the temperature difference can be achieved to be 60 K from 320 K. The electric power consumption is about 70 W for Qmax operation. The heat pipe is the effective instrument to transfer the heat flux, but it needs large area to contact the basement. In order to get the wide area for the HP, the PM is used and connected two bases like Fig. 4. The temperatures difference of T_1 and T_2 is around 2 to 3 K in the actual operation. Therefore, we can install many HPs to the cooling unit. Finally, we can establish the effective cooling for the CPU.

However, the electric power consumption of the cooling unit is almost same as the CPU's. And if we apply the cooling unit for the high performance and high power consumption CPU, the cooling unit is not effective because Qmax is lower than the power consumption of the CPU. Moreover, when the power consumption of the CPU is lower, the dew drop was found inside the computer.

Since the actual operation is almost "*Qmax* operation", and it means that the temperature difference between two sides of the PM is zero, one of our proposals to solve these requirements is to use "thin PM". In order to understand the problem, we should start the heat flux and voltage equation given by

$$\begin{aligned} Q_{\max} &= \alpha \times T_j \times I - \frac{1}{2} \times r_e \times I^2 - K \times \Delta T \\ &= \alpha \times T_j \times I - \frac{1}{2} \times r_e \times I^2 \quad for \;\; \Delta T = 0 \\ Voltage &= r_e \times I + \alpha \times \Delta T \\ &= r_e \times I \end{aligned} \tag{2}$$

where α is the Seebeck coefficient, *Tj* is the junction temperature, *I* is the current, r_e is the resistance of the PM, *K* is the thermal conductance and ΔT is the temperature difference between two sides of the PM.

The present thickness of the BiTe leg is 1.5 mm in Fig. 4, and if we shorten the leg of leg of the PM for "*Qmax* operation", *Qmax* will increase along the decrease of the leg of BiTe, and the electric power consumption can be decreased. The simple calculation result shows in Fig. 5. If we cut to the leg of 0.3 mm from 1.5 mm, the power consumption is to change from 70 W to 14 W, and the *Qmax* increase to be 90 W from 60 W. Therefore, we can apply the present high performance CPU. And we do not need to use a larger fin because the total power consumption decreases. Moreover, since the maximum temperature difference of the PM cannot exceed 20 K, it is not needed to pay attention for the dew drop inside the PC.

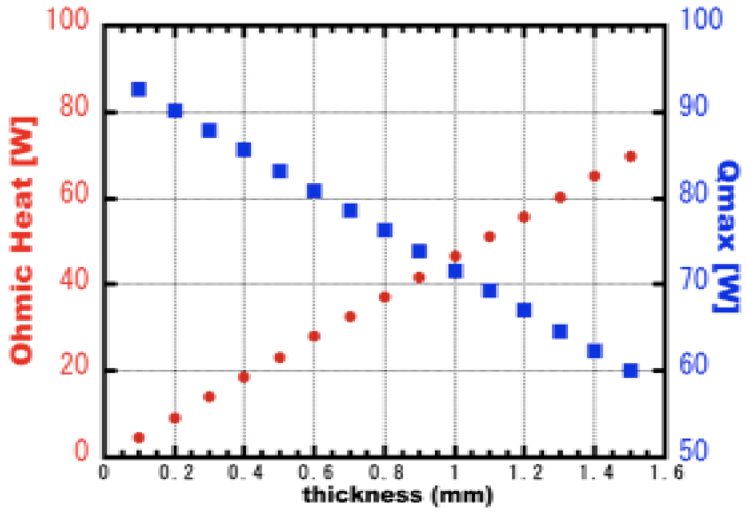

Figure 5 *Qmax* and power loss of the PM versus thickness of BiTe alloy.

The technology of a short leg PM is sometimes difficult, but the leg length of 0.2 to 0.3 mm is achieved [5] in the present time. Therefore, this proposal is one of the actual solutions to use the PM in the cooling system of the CPU.

DISCUSSION AND FUTURE STUDY

It is hard to buy a thin PM for this kind of application, and therefore we could not do the experiment in the present time. But this application will have larger market, and we try to do the experiment by the help of the PM maker. Here, we come back the principle of the cooling for electronic devices, such as CPU, IGBT and power MOSFET. The PM is not used to cool down these devices in the present time, but if we can apply the PM, high performance devices will be realized. It is believed that a material of high Seebeck coefficient, low electrical resistivity and low thermal conductivity is better as a Peltier material. It is true if the object should be kept lower than room temperature. However, when we cool down the object which temperature is higher than room temperature, it is not always true. See figure 6.

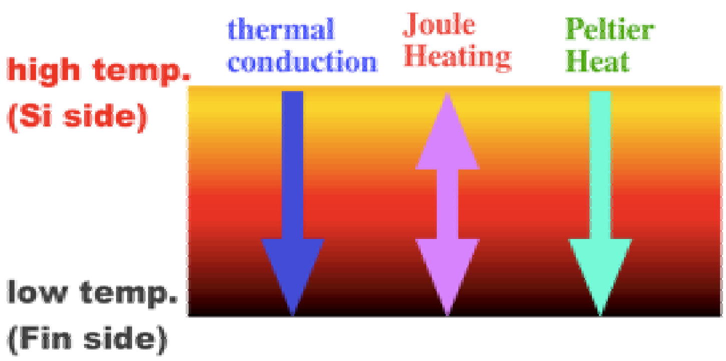

Figure 6 Optimum Peltier material to cool down high temperature object.

The temperature of electronic device side is higher than room temperature, and room temperature side is cold side of Peltier material in this figure. In order to remove heat from hot side, it is clear that the material of high Seebeck coefficient, low electrical resistivity and high thermal conductivity is better in Fig. 6. It means that we always do not need high Z material, and we need high power factor and high thermal conductivity. The thermal conductance of the PM is not included in Eq. (2) because of the Qmax operation. And a thermal conductance of thin BiTe alloy is high. This means that it is useful to apply high thermal conductivity material. Usually, the material of the heat spreader is the copper because its thermal conductivity is high.

If the above assumption is correct, we believe that we can find a material to realize these conditions because high thermal conductivity and low electrical resistance is not contradicted in the common sense of Thermoelectrics. But we need to do the experiment to demonstrate the principle of this idea. One of candidate material of the proposal is silicon carbide (SiC) [6], the thermal conductivity of single crystalline SiC is almost same as that of copper, and the power factor of single crystalline SiC is the same order of the BiTe alloy's [6]. In this meaning, SiC will be one of the ideal materials of this kind of application.

The geometrical structure of the cooling unit is important, and we should change the structure of the cooling unit along the transport parameters of Peltier material. For example, we can increase the attached area of the HP in Fig. 4, but it is only twice. Therefore, the actual application depends on the structure of the cooling object, too.

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