

Activities and Future Vision of Komatsu Thermo modules

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Abstract

This paper presents an introduction of Komatsu Electronics Inc., its history, activities, and future vision.

Firstly, the history of Komatsu thermoelectric modules will be presented. As one of the oldest thermoelectric related companies in the world, we might say that our history is the history of the thermoelectric industry.

Secondly, the current activities of Komatsu Electronics and our estimation of the industry's situation will be presented.

Lastly, our view of the future thermoelectric industry will be presented.

Outline of Komatsu Electronics

Komatsu Electronics Inc., abbreviated to KELK, was established in November, 1966. It is located in Hiratsuka city, Kanagawa pref., Japan.

It is a 100%-owned subsidiary of Komatsu Ltd., the construction machinery company, which has several electronics related companies as shown in Table1.

Table1 Komatsu electronics related group company

Company Name	Products
Komatsu Electronics Inc.	TEC, Temperature Control Equipments
http://www.komatsu-electronics.co.jp/	
Komatsu Engineering Corp.	Laser Marker, Sorter
http://www.komatsu-keg.co.jp/	
Gigaphoton Inc.	Excimer Laser for Lithography
http://www.gigaphoton.com/e/index.html	
Komatsu Machinery Corp.	CZ Puller, Polisher
http://www.komatsu-machinery.co.jp/HP/english/top_e.html	



Fig.1 Komatsu's Research Division

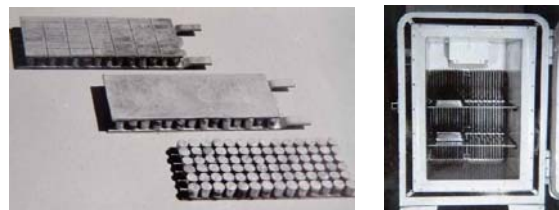
As one of the group company, KELK has been supported by the Research Division of Komatsu Ltd., shown in Fig.1, and part of our R&D activity is implemented in cooperation with them.

Taking our company's motto of "Create Temperature, Create by Temperature" as a mission since foundation, KELK has been devoted to providing a wide range of products in order to be the world's leading and most reliable supplier of precise thermal control systems based on thermoelectric modules with outstanding quality and innovative technology.

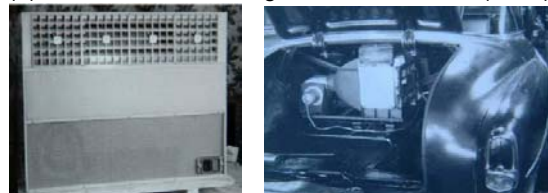
History of Komatsu Thermo Module and KELK

In Komatsu, experimental research into thermoelectric semiconductors began in 1957⁽¹⁾.

Mr. Y. Kawai, then president of Komatsu Ltd., had great interest in thermoelectric coolers (TEC) that were being researched at Univ. of Tokyo and was eager to develop household appliances like air conditioners and refrigerators (Fig.2).



(a) TE Module and Refrigerator with Ice Box (1958)



(b) TE Air Conditioner for Room and Car (1958)

Fig.2 Products developed initially at Komatsu

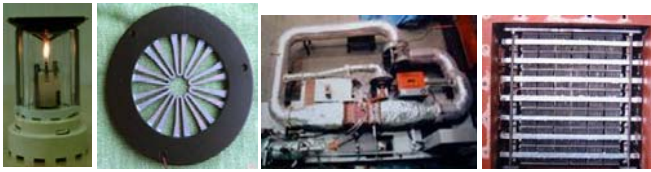
In 1959, Komatsu got the first order for TE modules. TE-cooled photoelectric photometer housing was manufactured for the equatorial telescope of the Tokyo Astronomical Observatory.

In the 1960's, many companies entered the TE industry but then quit, and there were few companies left in the 1970s. This was because most of the companies were consumer electronics makers and most consumer TE cooling systems could not compete with vapor compression cycle systems⁽²⁾.

KELK found its way in the 1970s to semiconductor equipment like Chemical Circulators that were the successor of the COOLNICS chiller series developed in 1963.

In the 1980s, after the oil crisis, KELK developed many thermoelectric generation (TEG) systems. For example, candle type Fe-Si TEGs were developed and mass produced, and research was carried out on TEG systems using low grade

waste heat from electric power plants, under a contract with Tokyo Electric Power (Fig.3).



(a) Candle type TEG (b) TEG for power plant
Fig.3 TEGs developed in the 1980s

Current Activities of Komatsu

Through the history described above, KELK has become a fully integrated manufacturer of temperature control products. This means KELK researches, develops, and manufactures thermoelectric materials, modules, heat exchangers, and temperature control equipment (Fig.4).

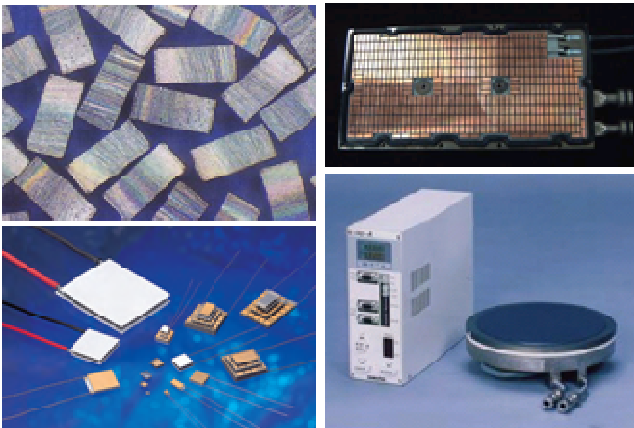


Fig.4 Clockwise from upper left: Thermoelectric elements, heat exchanger, temperature control plate, and thermoelectric modules

Using this technology expertise, one of the main businesses of KELK are various temperature control systems for semiconductor manufacturing processes shown in Fig.5.

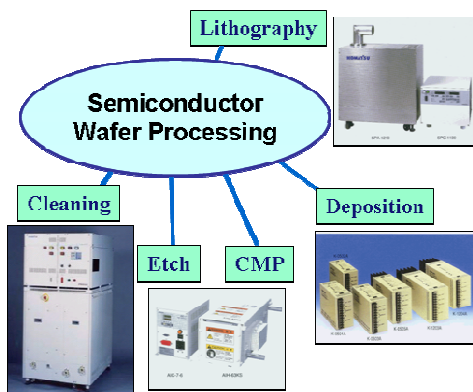


Fig.5 Semiconductor processes and the thermal solutions

Another main business is sales of thermo modules themselves as TECs. KELK has a wide range of TEC products.

To make full use of the feature of TECs, that is, being able to reduce the size without reducing the performance, one of

their best applications must be thermal control of small electronic devices.

The main motives for thermal control of electronic devices can be divided into two, one is for longer operating life and the other is for device performance.

Some examples follow.

(a) Longer lifetime for laser diodes

The emitting region of laser diodes is very small and their thermal conductivity is not so large. Their conversion efficiency is only 15-30% but high power is applied. Therefore their temperature is easy to rise. Generally their lifetime shortens to 1/10 for every 20K increase and their temperature is usually controlled down to as low as 25-35°C.

(b) Performance and lifetime of CPUs

It is well known that the transistor density of CPUs is getting higher and higher in order to improve their performance. However this causes higher heat density than radiation performance which leads to lower CPU performance. In addition high temperatures cause CPUs to reduce their life expectancy.

(c) Noise reduction of high-end CCD cameras.

Dark current or thermal noise in CCDs is generated by quantum effects at the silicon dioxide interface below the parallel gate structure. Generally, dark current doubles when temperature rises 6 to 10 K. For this reason, CCDs are cooled for the use of long exposure modes, taking weak light such as from astronomical telescopes or fluorescence microscopes. Multi stage TECs are used to cool CCDs from at least -25°C down to -100°C.

(d) Wavelength control of source laser diodes for DWDM

In DWDM telecommunication systems, hundreds of different wavelength lasers are input into a fiber together. Wavelength spacing is only 0.3nm but the laser wavelength shifts 3nm for every 10 degree temperature shift. The temperature of the laser diode should be precisely controlled to $\pm 0.2K$.

Advantages of Komatsu's Thermo modules

As described above, Komatsu have been looking for new uses for thermo modules and it is a factor of survival. But Komatsu has some competitive advantages in the thermoelectric module itself, material processes and module assemble technology to name a few.

(a) Material processes

Sintered BiTe had been developed at Borg-Warner Corporation in the 1960's, however the production process was not publicized. Even in 1989, few companies used sintered BiTe and its performance was not good compared to commonly used crystalline BiTe.

We have applied the hot press process to enhance performance, and have been continuously improving the performance for 14 years. Fig.6 shows the progress of coefficient of merit Z calculated from module ΔT .

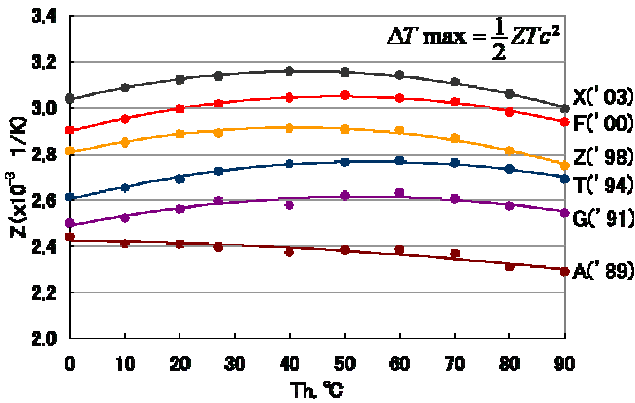
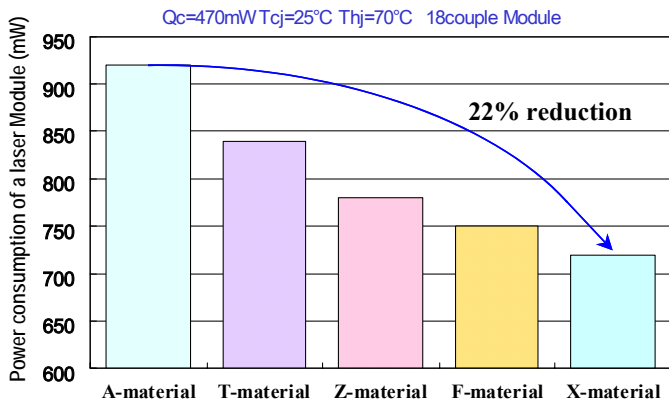


Fig.6 Material improvement over 14 years

The established mass production process includes plastic deformation, and we have succeeded to increase the maximum temperature difference by about 15°C from the start point, and achieved a 22 percent reduction in power



consumption for the same TEC design (Fig.7).

Fig.7 TEC power consumption with each material

(b) Module assembly

Komatsu started robotic assembly in 1989.

Using robots, accurate and consistent positioning of elements are realized. It also enables us to offer a huge variety of module designs as well as high density assembling.

As a result, our micro modules have a high performance, consistent mass volume reliability, and excellent cost competitiveness. Fig.8 shows the production line.



Fig.8 TEC robot assembly line in KELK

Current Situation of the Thermoelectric Module Industry

Fig.9 shows an estimated market distribution based on the sales value of thermo modules.

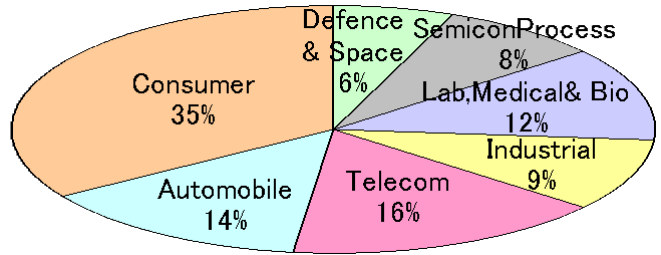


Fig.9 Market distribution of thermo module

The estimated sales in FY2006 are around \$200 million. The market has grown more than 5 times than that Burton⁽³⁾ indicated in 1989. The growth has been amazing though, of course, these data cannot be compared with each other as the methods of estimation are not the same. The primary factors of growth are the performance and cost of the modules. These factors are pointed out in Burton's papers.

Defence and space used to be the center of the market. It is still a steady market but is not growing. The private sector has been growing in these 10-20 years.

Now the consumer market is the largest domain. This includes water coolers, cooler boxes, refrigerators etc. The unit price is very low and most of the products are made in China.

The automobile market is growing, especially for luxury automobile's seat coolers. There must be another application in the car industry.

There are so many applications for lab., medical and bio. equipment but the demand for each application is not so big.

Small modules are needed for the telecom market. After the telecom bubble, the market shrunk to almost zero. Now it is growing again though not rapidly.

The future of the Thermoelectric Module Industry

(a) Consumer market

A certain and steady market will exist. Water coolers and cooler boxes will remain at the center of this market. They make the best use of TECs' advantages by cooling specific goods a small amount, especially wine cellers and cosmetic coolers.

In the consumer market, "peltier modules" still have a good image as state of the art technology and companies are trying to introduce them into more and more products.

(b) Electronic devices

This is very exciting market. Technological innovation is very fast and markets appear and disappear depending on the device innovation. One direction is the miniturization of TECs with the progress of high density packaging. So far, our design has been achieving not only downsizing but also higher heat density. Under these conditions, material performance is important as well as interfacial materials with higher thermal conductivity.

(c) Thermoelectric generator

At this moment, the market for thermoelectric generators (TEGs) is very small compared to TECs. The market is divided into that of tiny remote power sources and that of waste heat recovery. For the former, there are some examples

like corrosion protection for gas pipelines. For the latter, TEGs have not yet satisfied the required performance both as a material and as a system.

Komatsu have been participating in the NEDO TEG project and have improved module efficiency to 7% for both BiTe type and silicide type materials as shown in Fig.10 and Fig.11. Komatsu also have been developing systems with these modules.

The future of TEG looks promising enough and the

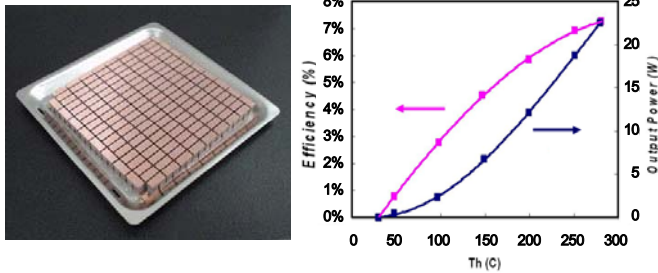


Fig.10 BiTe Thermoelectric Generator

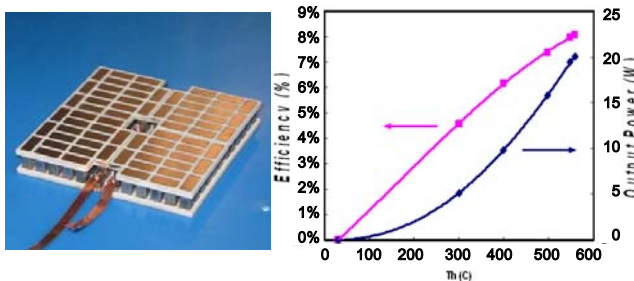


Fig.11 Silicide Thermoelectric Generator

authors believe the market size will become several times more than that of TECs. There are high expectations for ubiquitous batteries for tiny remote power sources. For waste heat recovery the authors believe TEGs will be an indispensable technology for the 21st century, the century of the environment.

Problem of the Thermoelectric Module Industry

One of the problems against the future development of thermoelectric modules is the availability of raw materials.

There are 4 main raw materials used in thermoelectric elements, Te, Bi, Sb and Se. These are regarded as rare metals and their supply may be limited in the future (Table2). What is worse is that main application of these materials is additional agent of some sort and it is difficult to recycle.

Recently their market prices have risen rapidly even tenfold and fluctuated noticeably. In addition these materials may be considered as pollutants or toxic so some of them might be prohibited.

For these reason, we needs and expects the development

Table2 Raw materials of thermoelectric elements

Element	Production 2005(ton)	Reserves (ton)	Available period	Application in Japan Top use	TEC's demand Ratio
Te	200	21,000	105 years	Addition agent(67%)	10%
Bi	5,500	320,000	58 years	Addition agent(25%)	<1%
Sb	137,000	1,700,000	12 years	Fire retardant(86%)	<1%
Se	1,390	82,000	58 years	Chemical agent(12%)	<1%

of other types of materials for the future of thermoelectric industry.

Conclusions

In this paper, the history and current situation of the thermoelectric industry have been described. Starting around 1960, going through tough times, the industry overall is growing steadily, although its market size is not big.

For a certain kind of product, TECs have firmly established their position making use of their advantages. In addition they are being applied to a wide range of new products.

With this current situation and the prospect of future applications, the authors think the future of the industry is promising.

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