HISTORY OF THERMOELECTRICITY DEVELOPMENT IN JAPAN

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- *General idea of thermoelectricity development in Japan by illustrating the case of its pioneer, Komatsu Co. Ltd. and its subsidiary Komatsu Electronics Inc.*

Introduction

Research into thermoelectricity in Japan dates back to half-a-century ago. Professor Y. Suge and Instructor M. Aoki of the University of Tokyo started the research on thermoelectric (TE) semiconductor materials for cooling at their Applied Physics Laboratory in 1955. At the time it was hard to obtain raw materials of high purity such as tellurium, bismuth etc. from the mine companies in Japan. These raw materials contained considerable amount of harmful impurities, Cu, Ag, Pb etc. The figure of merit, Z of the TE couples using the n and p material prepared by zone-melting techniques with these raw materials were no more than $Z=0.9x10^{-3}K^{-1}$ ($\triangle T_{max}=30K$ at $T_h=300K$ in vacuum). It was necessary to get higher $Z=2x10^{-3}K^{-1}$($\triangle T_{max}=58K$ at $T_h=300K$ in vacuum) to purify the raw materials using zone-refining or distillation apparatuses that were of their own making.

Mr. Y, Kawai, then the President of Komatsu Co., Ltd., leading bulldozer manufacturing company in Japan, had great interest in the TE experiments in the University of Tokyo. He was eager to put TE to commercial usage. The Komatsu developed R&D project to improve the figure of merit, Z of TE materials and to produce household TE appliances, particularly TE air conditioners and TE refrigerators using TE modules in 1957.

At that time, contrary to his expectation, large-scale consumer TE cooling could not compete with vapor compression cycle systems. However, Komatsu continued its efforts in the aim of broadening TE cooling applications in a wide variety of fields.

Concerning the TE power generation in Japan, the basic researches were carried out on Pb-Te, transition metal silicides, Cr-Si, Co-Si, Mn-Si etc. by Dr. T. Sakata and Dr. I. A. Nishida of the National Research Institute for Metals (NRIM) since 1950s.

Since Japan is small island country and had nothing to do with space development programs and military-related industry in those days, it was difficult to cultivate a market for the TE power generators. In 1973 and 1979, we experienced two oil crises that gave us a great shock because Japan was heavily dependent on the Middle East for petroleum resources. At the same time, it gave Japan a good opportunity to recognize how energy resources were important for us. Since 1980s, meetings or symposiums on thermoelectric energy conversion

started to be held by the scientific societies in Japan.

History of Thermoelectricity Development in Komatsu, Japan

The progress in Thermoelectricity Development in Komatsu, Japan is described in chronological order below.

1956:

Research Laboratory on thermoelectricity was established in Komatsu.

1957:

R&D project on TE cooling commenced. The subjects were as follows:

- Purification of raw materials, *Bi, Te, Sb* etc.
- Increasing Z value of $(Bi,Sb)_2(Se,Te)_3$ ingot.
- Manufacturing of TE elements and thermo-modules.
- Heat transfer technologies.
- TE cooling applications, particularly refrigerators and air conditioners.

1958:

High current (I_{max}=~30A) modules without ceramic substrate were developed. TE refrigerator, TE room air conditioner, TE car air conditioner and TE portable cooling box for car were manufactured using them on a trial and test basis (Fig. 1 - 4).

1959:

TE-cooled photoelectric photometer housing was manufactured for the equatorial telescope of Tokyo Astronomical Observatory at Okayama, Japan [3]. It gave low noise, low dark current operation, gain stability and signal-to-noise ratio improvement for the photomultiplier measurement [Fig. 5]. It was the first business activity of Komatsu.

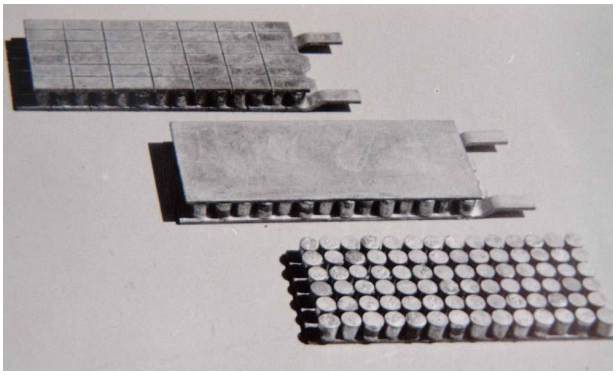
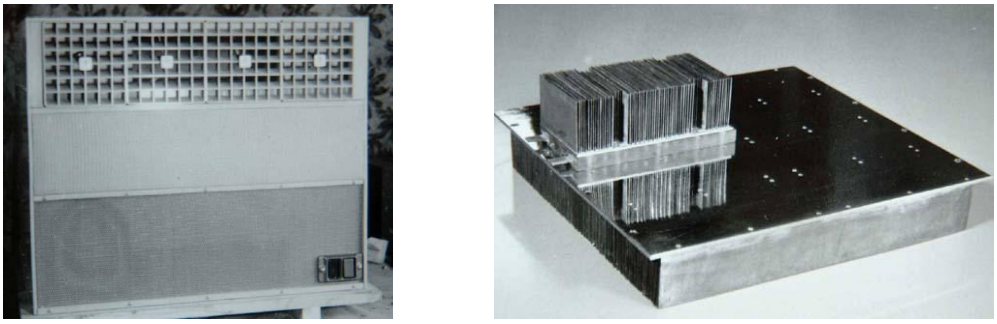


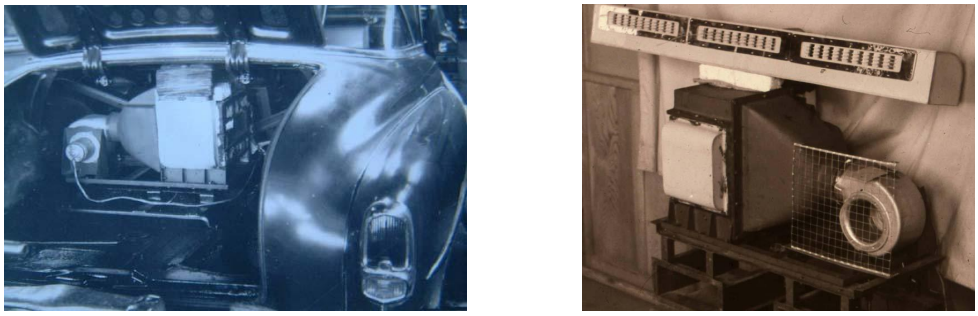
Fig. 1. TE module (I_{max}=20A, 36 couples) (Komatsu, Japan, 1958)

Fig. 2 TE Refrigerator with Ice Box (Komatsu, Japan, 1958)

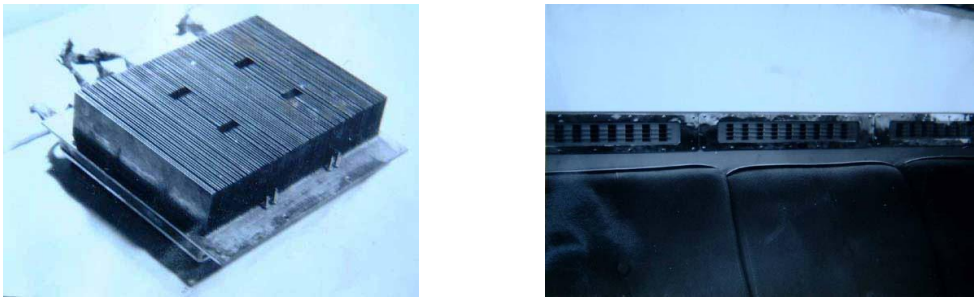


a) *b)*

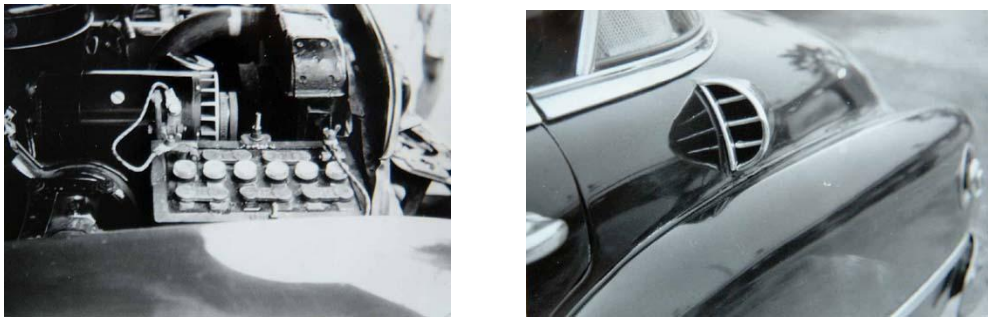
Fig. 3. TE Room Air Conditioner (Komatsu, Japan, 1958)
a) Room Air Conditioner; b) TE Cooling Unit



a) *b)*



c) *d)*



e) *f)*

Fig. 4. TE Car Air Conditioner (Komatsu, Japan, 1958)
a) TE Car Air-conditioner in Chrysler Trunk; b) TE Air-conditioner; c) TE Cooling Unit;
d) Cold-air Ventilator behind Rear Seat; e) Supplemented Dynamo in Engine room;
f) Outside air intake into Chrysler Trunk

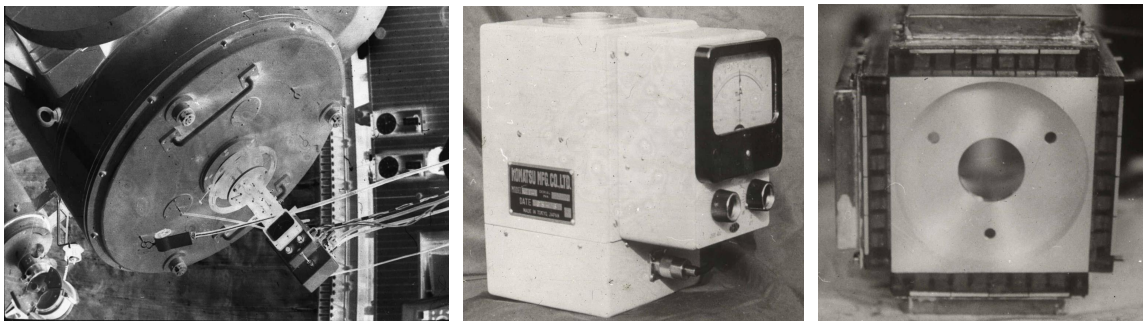


Fig. 5 TE cooled 91 cm Reflector at Tokyo Astronomical Observatory, Okayama, japan (Tokyo Astronomical Obsevatory and Komatsu, Japan, 1959).

1960 - :

Subsidiary company, Komatsu Electronics Inc. (KELK) was established in 1960 and started R&D, manufacturing and business activity of thermo-modules and TE cooling applications in a wide variety of fields including astronomy [1], electronics [2], space [3, 8], medical and medical treatments [4], agriculture and forestry [5], biotechnology [6], optical communications [7], meteorology [9], satellite communications [Fig. 8] and laboratory [12] etc.

1961:

Microscope Stage TE Cooler which is an instrument for cutting sections of frozen tissue for microscopic study was developed. It was produced according to every one-year plan under the exclusive contract with the Yamato Optical Instruments Co., Ltd., Japan.

1963:

The standardized temperature-control TE equipments were developed. Their brand names were “COOLNICS CIRCULATOR”, “COOLNICS AIR”, “COOLNICS THERMO BATH” and “COOLNICS DIP”.

Coolnics Circulator: Constant temperature liquid circulator.

Coolnics Air: Constant temperature air chamber.

Coolnics Thermo Bath: Constant temperature liquid bath.

Coolnics Dip: Dip-type liquid temperature controller.

These equipments were on sale in all parts of Japan through distributor, Yamato Scientific Equipments Co., Ltd. under the exclusive every one-year contract. These equipments were the prime mover of TE applications in Japan.

1963 - 1965:

Production research was carried out on one tip press-sintering of *Bi-Te, Pb-Te* TE elements and hot-pressing of *Mn-Si, Co-Si* TE materials.

1967 - :

Basic Law for Anti-pollution Measures was enacted in 1967 in Japan. TE

dehumidifiers were produced for atmospheric pollution gas analyzers, e.g. infrared gas analyzer etc.

1970 - :

Development of Super LSI was National Project of Japan. TE temperature controlled (± 0.1K) etching solution circulating & filtering (0.2 μm) systems and TE controllers of dopant were manufactured for production of Super LSI and other semiconductor devices in Japan. [Fig. 6, 7]

Fig. 6. TE Chemical Circulator (KELK, Japan, 1970)

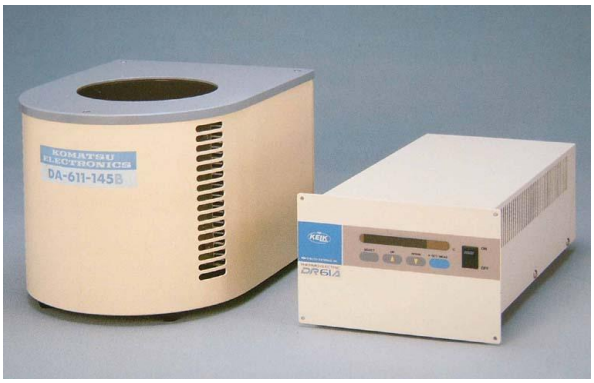
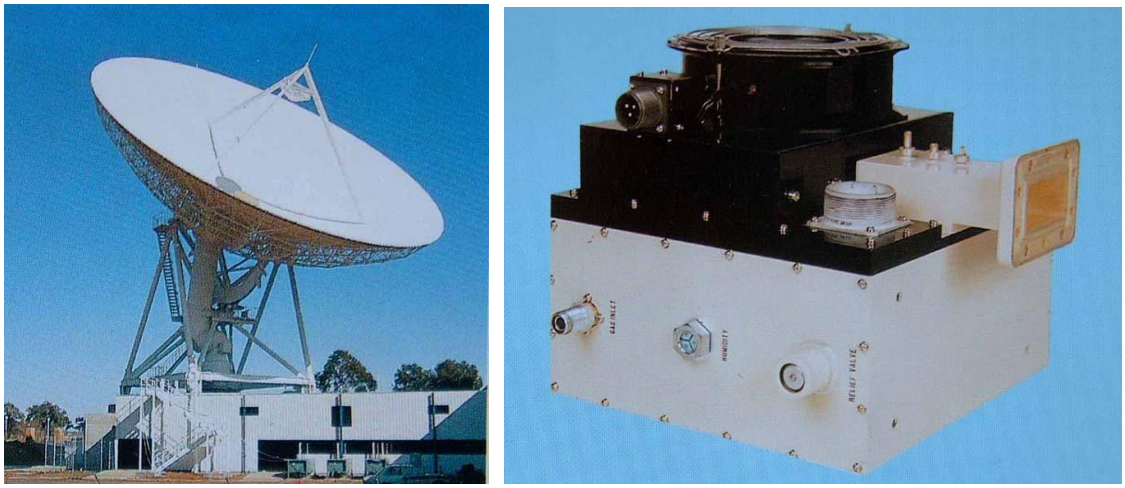


Fig. 7. TE Bath for Dopant (KELK, Japan, 1970)

1972:

Three stage cascaded TE cooling units were developed by KELK for LNA (low noise amplifier) of Satellite Communication Ground Facilities which were established on every corner of the earth by NEC, Japan [Fig. 8].



a) b)

Fig. 8. Satellite Communication Systems (NECAND KELK Japan, 1980)
a) Parabolic Antenna (NEC); b) LNA cooled with 3-stage Cascade TE Unit

1980 - 1982:

Participated in the OTEC (Ocean Thermal Energy Conversion) Project which was conducted as part of the MITI Sun Shine Project. 500 units of TEG module were manufactured by KELK. OTEC Plant was constructed in the premises of Kawasaki Heavy Industries Co., Ltd. Japan and test run was performed. Cooperated organizations were MITI, Engineering Advancement Association, Kawasaki Heavy Industries Co., Ltd. and KELK [Fig. 10]

Bi-Te element size: 10 x 1.5 mm.

Total number of *n-p* couples: 10,000 couples/

Number of TEG modules: 500 modules.

a)

b)

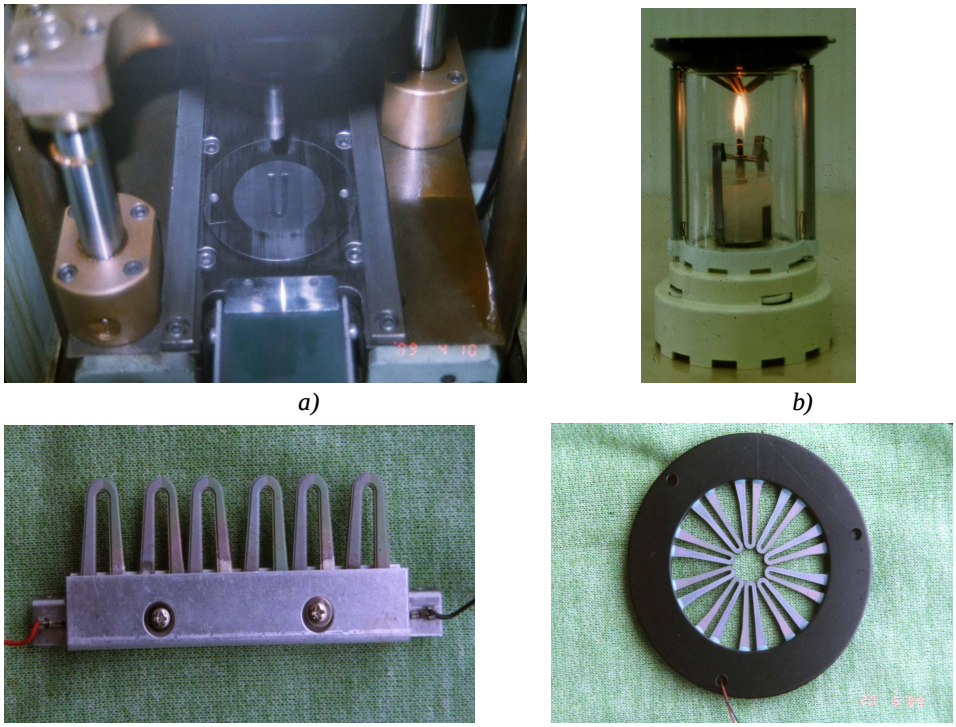
c)

Fig. 10 OTEC Test Plant (MITI, Engineering Advancement Assoc. Kawasaki Heavy Ind. Co., Ltd. and KELK, Japan, 1980) a) OTEC Test Plant; b) Stacked OTEC TEG Units; c) OTEC TEG Unit (KELK, Japan, 1980)

Commercialization of press-sinter *Fe-Si* couples for TE power generation was started under the licence of the NRIM (National Research Institute for Metals) [6].[Fig. 11]

1983:

Experiment on artificial snow crystal growth under zero gravity in Space Shuttle, Challenger was conducted by NEC, Japan using KELK thermo-modules [Fig. 12].



a) *b)*

c) *d)*

Fig. 11. Press-sintering of Fe-Si p-n Couple (KELK, Japan, 1980)
a) Cold-pressing of Fe-Si Couple; b) Candle-type Fe-Si TEG;
***b)** Series-type Fe-Si Module; d) Circular-type Fe-Si Module.*

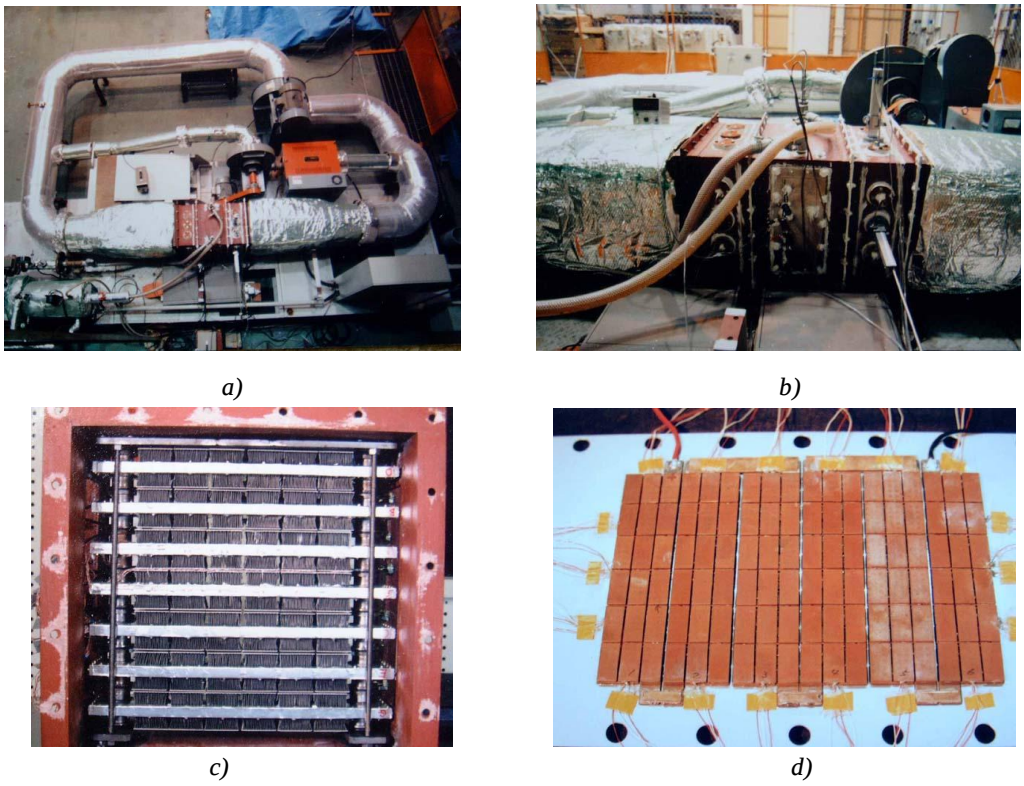
Fig. 12. Artificial snow crystal growth experiment under zero-gravity in Space Shuttle Callenger.
(NASA, USA, NEC and KELK,Japan, 1983)

1984 - 1986:

Researches were carried out on TE power generating systems using low-grade waste heat.

- waste heat from electric power plants, under a contract with Tokyo Electric Power

Company [Fig. 13].

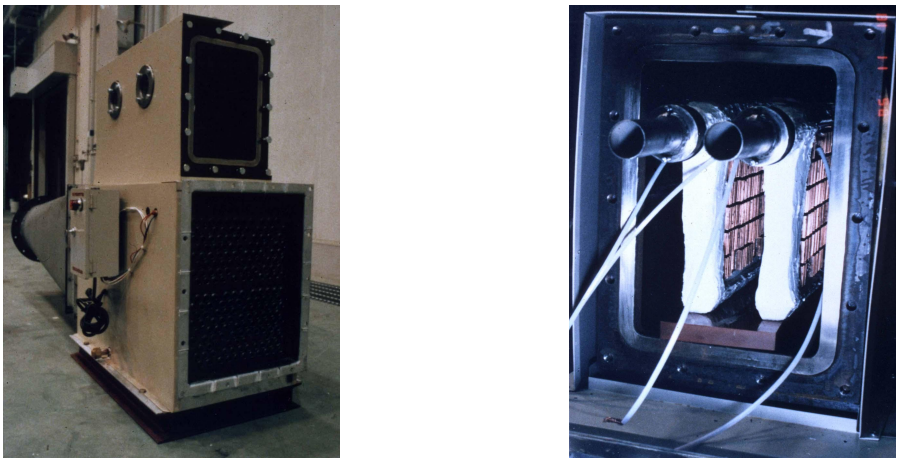


a) *b)*

c) *d)*

Fig. 12. Experimental TEG utilizing waste heat from Electric Power Plant (under contract between Tokyo Electric Power company and Komatsu Research Center, KELK, Japan, 1984)
a) TEG test facilities; b) TEG mounted into hot gas duct; c) TEG system; d) TEG modules

- heat was collected using thermo-siphon method, under joint research between Komatsu Research Center and KELK [9] [Fig. 14].

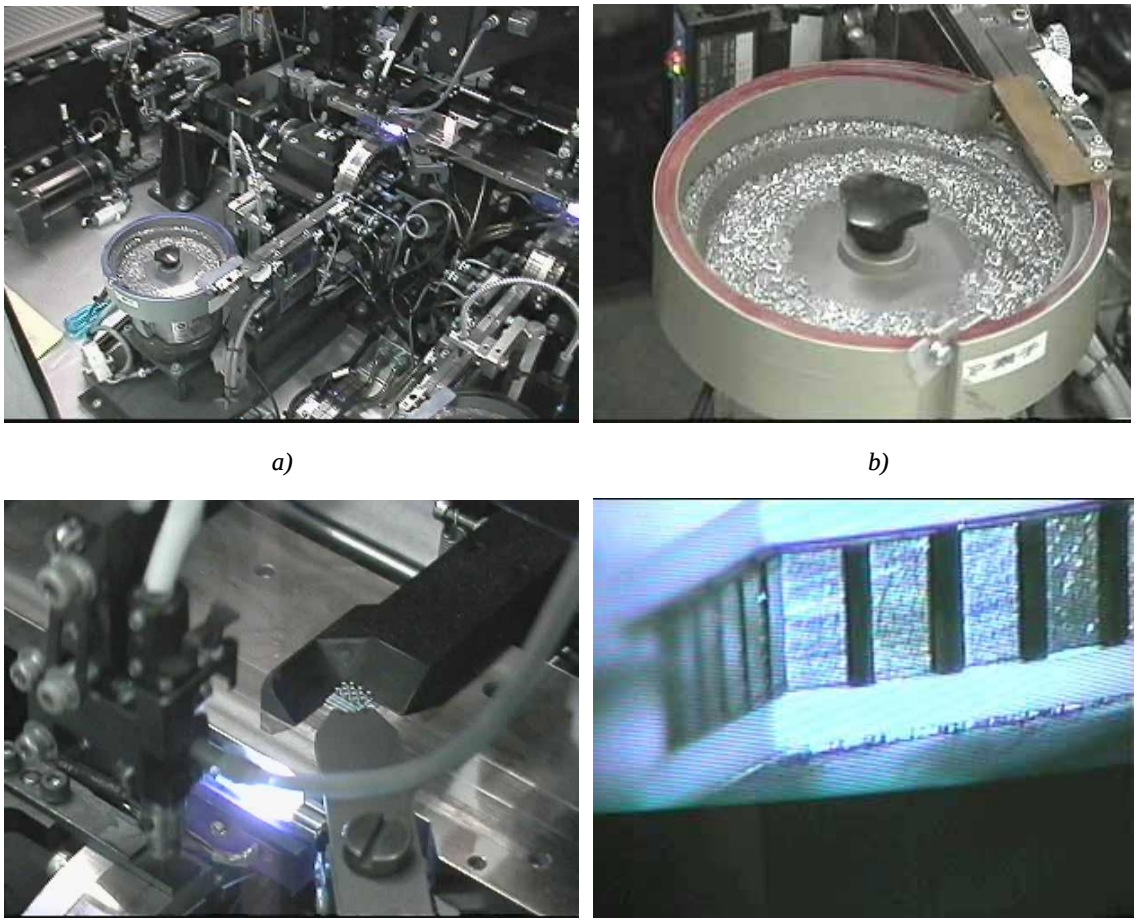


a) *b)*

Fig. 14. Experiment on Thermo-siphon type TEG system utilizing Low Grade Heat Source. (under joint research between Komatsu Research Centerand KELK, 1985)
a) Thermo-syphon TEG system; b) Thermo-syphon TEG units)

1989:

Robot production facilities were provided for assembling Micro Modules [6, 7]. KELK Micro-modules have come into wide use for stabilizing temperature of Optical Communication Laser Diodes in the world [Fig. 15].



a) *b)*

c) *d)*

Fig. 15. Robot assembling of TE Micro-modules (KELK, Japan, 1989 -)
a) Robot facilities for assembling TE Micro-modules; b) Feeding of elements;
c) Pick and place of TE elements; d) Robot assembled Micro-module.

1990 - :

Regarding the latest(1990 - to date) TE products of Komatsu Electronics Inc., see the web site http://www.komatsu-electronics.co.jp/english/index.htm

Acknowledgment

Author would like to express his gratitude to Organizing Committee of the "X International Forum on Thermoelectricity" and Mr. Y. Kibayashi, Director of Komatsu Electronics Inc. who proof-read this paper and gave his willing agreement to present it at the Forum.

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