State-of-the-art Technologies of Micro Heat-Pipe Heat-Sinks for Notebook PCs

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ABSTRACT In recent years, the heat produced in notebook PCs has increased rapidly along with the upgraded speed of the MPU, making heat dissipation measures thereof indispensable. Micro heat-pipe heat-sinks which are capable of dealing with this problem have been in practical use since 1995. Conventional heat-sinks, however, can no longer provide sufficient cooling for the latest version of MPUs in notebook PCs where increased heat production is seen caused by high-performance peripheral components. This paper reports on the technological background of micro heat-pipe heat-sinks for notebook PCs together with fin-composite micro heat-pipe heat-sinks that are expected to dominate the field of heat-sinks of the next generation.

1. INTRODUCTION

As computers improve in speed and performance, the heat produced by the micro processing unit (MPU) increases rapidly, making heat dissipation measures urgently needed. With notebook PCs where heat dissipation poses a problem due to their small packaging volume, in particular, heat dissipation technology has become one of the key technologies. Micro heat-pipe (hereafter denoted as μHP) heat-sinks which are capable of dealing with this problem have been in practical use since 1995.

μHP generally refers to small heat pipes with a diameter of 3 to 6 mm, which permit easy bending and flattening, and is applicable to thermal wiring for heat dissipation. In practical applications, μHPs are combined with thin metal plates, die casts, fans and rubber to comprise a variety of heat-sinks of compact size. In recent years, appreciated for their advantages, μHPs are well on their way to practical applications in the fields of information oriented home appliances and multi-media terminal equipment, in which small space for installation is essential.

At the time when μHPs were first employed for notebook PCs, the heat produced by the MPU was 5 to 6 W at most, so that μHP heat-sink products having a simple structure consisting of a μHP and a metal plate accounted for the main stream. MPU continued to improve in speed and performance after that, leading to an increase of heat production that is reaching 20 to 25 W with the latest models. Moreover, the MPUs now under development are estimated to produce an amount of heat of 30 W or more, raising the entire heat including that from other heat-producing components as high as 35 W approximately. Thus, it is anticipated that notebook PCs in the near future will face a difficulty in cooling the total system including MPUs, unless they employ advanced heat-sinks that combine μHPs and fans.

The present paper reports on the technological background of μHP-based heat-sinks, describes the structural changes in μHP-based heat-sink products until now, and introduces state-of-the-art technology together with innovative products that are expected to dominate the field of heat dissipation, including: heat-sinks using heat-pipes as small as 1 mm in thickness; heat-sinks that utilize heat-pipe hinges; and heat-sinks that use fin-composite μHPs having a multitude of fins mounted by a unique process.

2. CHANGES IN THE μHP HEAT-SINK PRODUCTS FOR NOTEBOOK PCS

Performance of heat-sinks has to be improved along with the increase in the heat produced in the MPU of notebook PCs. Figure 1 shows the changes in the μHP heat-sink products for notebook PCs, and the features of each generation are described below.

2.1 Heat-sinks of the First Generation

Heat-sinks of the first generation has a structure such that the heat produced in the MPU is transferred to the μHP through heat-receiving block, is diffused to the entire metal parts such as shielding case, and is dissipated from there by natural convection. The bottom of the housing or the rear side of a keyboard is often used as an area for heat dissipation. Heat-sinks of this generation, while being simple in structure, ensure sufficient cooling as long as an

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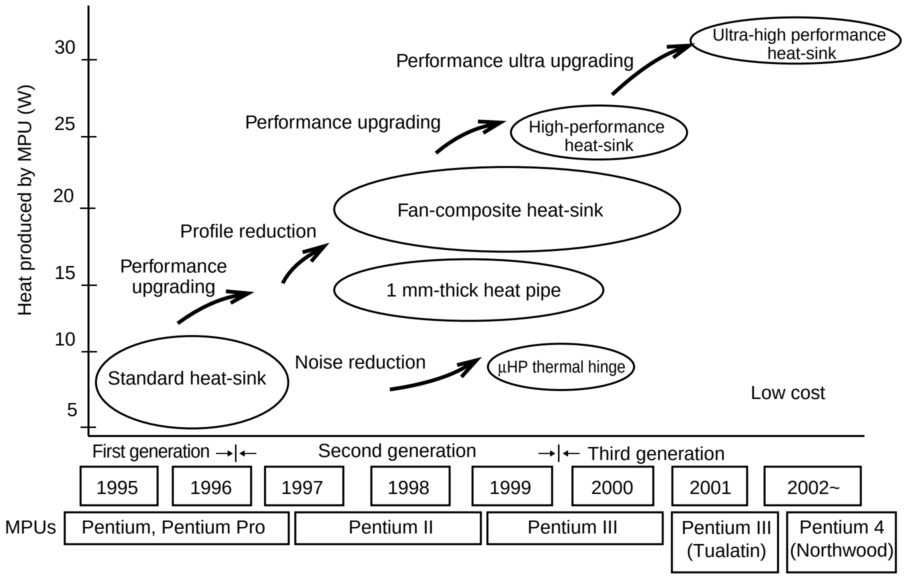


Figure 1 Changes in the μHP heat-sink products.

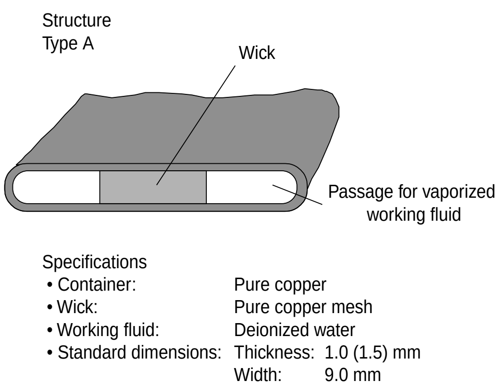


Figure 2 Structure of 1mm-thick μHP

area of adequate thermal margin is provided, so that they are still in use for various notebook PCs that employ MPUs of low heat production.

2.2 Heat-sinks of the Second Generation

As the heat produced by the peripheral devices and equipment besides MPU increases in notebook PCs reducing areas of adequate thermal margin, conventional heat-sinks --first-generation heat-sinks and those based on fans-- encountered difficulties in coping with heat dissipation. Accordingly, heat-sinks have begun to employ a new structure such that the heat produced by MPUs is transferred using μHPs to thermal fins located at the side portion of the housing securing a space, and is discharged outside thus effecting forced cooling. Meanwhile, since notebook PCs are increasingly required to be lower in profile and better in portability, new μHP-based heat-sinks are appearing to meet such requirements. They are: heat-sinks that use μHPs 1 mm in thickness enabling thermal wiring in limited places where conventional 2 mm-thick flat μHP is unsuitable; heat-sinks based on thermal hinges permitting efficient heat conduction to the display panel of PC when the housing main body only is insufficient in heat dissipation. These two heat-sinks are described in detail in Chapter 3, "STATE-OF-THE-ART TECHNOLOGIES OF μHP HEAT-SINKS".

2.3 Heat-sinks of the Third Generation

It is anticipated that even the heat-sinks of the second generation are going to be insufficient in coping with the ever increasing heat produced in notebook PCs in the near future. Only heat-sinks of the third generation are thought to be capable of managing such a situation. These heat-sinks are provided with high-performance fins of lightweight and compactness having a large working area per unit volume, which are installed at the outlet of a fan to achieve extensive improvement than ever in performance.

Thus, heat-dissipation technology represented by μHP heat-sinks has made a remarkable progress along with the improvement of MPUs. Chapter 3 describes some of the new products of the second and third generations representing the latest technologies for heat dissipation.

3. STATE-OF-THE-ART TECHNOLOGIES OF μHP HEAT-SINKS

3.1 Heat-sinks using 1mm-thick μHPs

μHP heat-sinks used in notebook PCs are required to be low-profiled in order to improve portability. A μHP having a thickness of as small as 1 mm --the thinnest in the world among practical μHPs-- has been developed to realize such heat-sinks.

Figure 2 shows the structure of a 1-mm thick μHP, which is characterized by providing a return passage for working fluid at the center and two passages for vaporized working fluid at the both sides. Figure 3 shows the maximum heat transfer rate of a 1 mm-thick μHP. The operating temperature within a typical notebook PC using such a

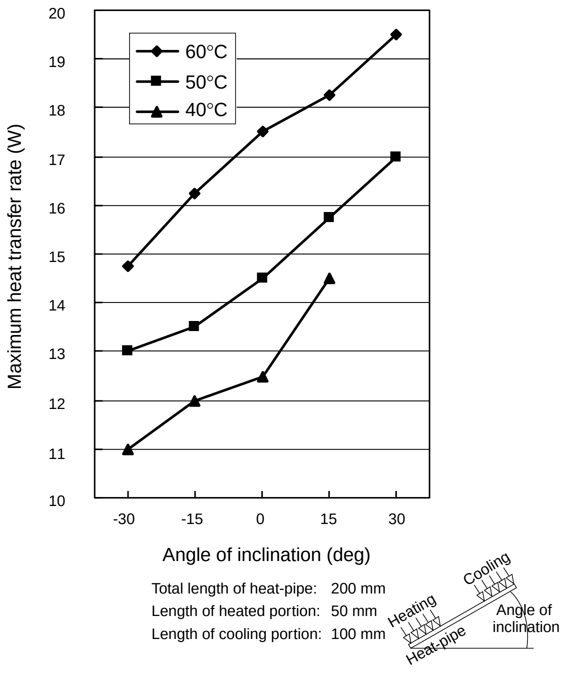


Figure 3 Maximum heat transfer rate of 1 mm-thick μHP.

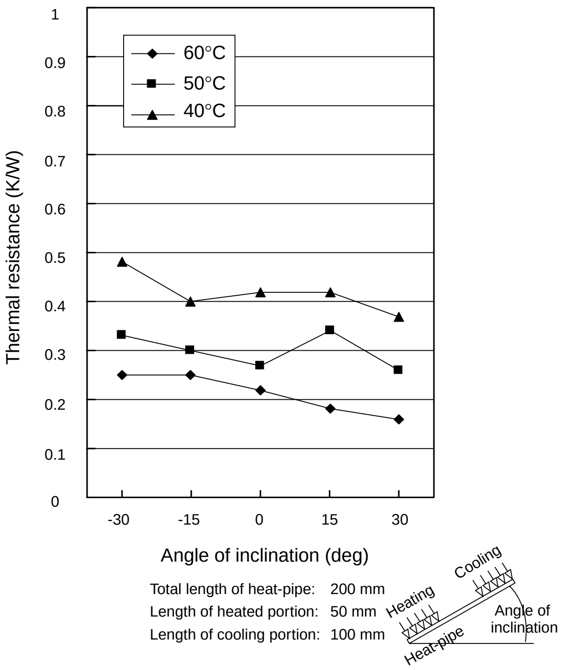
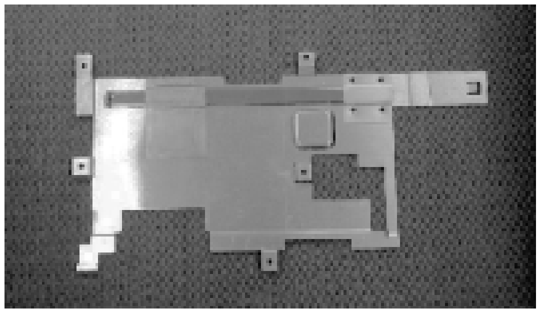


Figure 4 Thermal resistance of 1 mm-thick μHP.

1 mm-thick μHP is estimated to rise to 60~80°C. It is seen from the Figure that the maximum heat transfer rate of the μHP at this temperature is more than 18 W, so that a heat-sink with a heat-transfer capacity of around 35 W sufficiently capable of coping with the MPU's heat can be realized when metal plate or die cast is combined.

Figure 4 shows thermal resistance characteristics of a 1 mm-thick μHP. The higher the operating temperature, the lower should be the thermal resistance of 1 mm-thick μHPs for notebook PCs. The Figure shows such thermal characteristics, demonstrating the practical applicability of



Features
Small thickness of 1 mm
Applicable to bending process
Large heat transfer rate
Direct mounting to heat-producing devices permitted

Figure 5 Heat-sink using 1 mm-thick μHP.

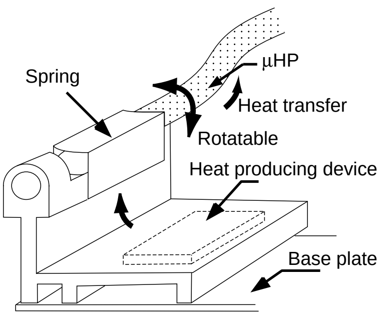


Figure 6 Structure of μHP hinge.

1 mm-thick μHPs.

Figure 5 shows a heat-sink using this 1 mm-thick μHP, in which fan was removed by employing the heat-sink to dissipate the heat of 8 W produced by the low-power consumption MPU newly developed.

3.2 Heat-sinks Using μHP Hinges

Conventional design of notebook PCs has usually been such that heat dissipation is effected on the main body (keyboard) side only. However, the heat produced by the main body has increased so much that sufficient heat dissipation through the limited area has become difficult, making it effective to dissipate the heat by conduction from the main body to the display panel where remains ample thermal margin.

Figure 6 shows the structure of a μHP hinge developed for such a purpose. The heat produced by the MPU is received by the μHP hinge assembly connecting the main body to the display panel, is transferred to the heat dissipating metal plate on the display panel where dissipation is effected. Thermal hinge structure of small heat resistance is therefore needed for practical application of μHP hinges.

Figure 7 shows the results of thermal experiments on a heat-sink having a structure of μHP hinge. It can be seen that the heat produced by the MPU on the main body is efficiently transferred under a low thermal resistance, which has been achieved by fastening the hinge assembly to the μHP using a specially designed spring thereby

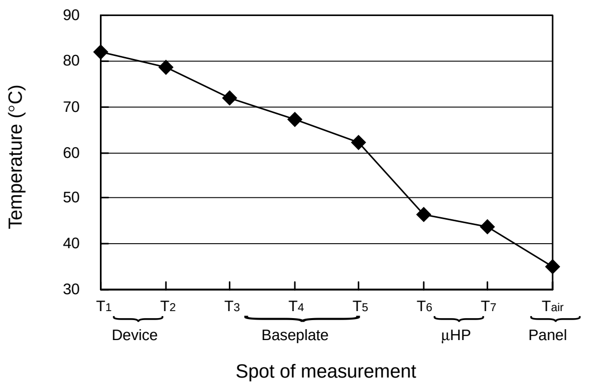


Figure 7 Results of thermal experiments on a heat-sink with μHP hinge.

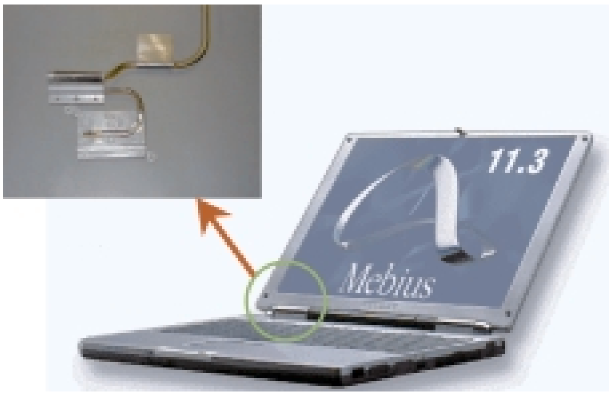


Figure 8 Appearance of a notebook PC using μHP hinge.

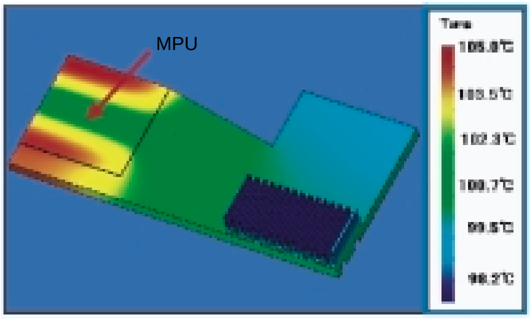
reducing the thermal contact resistance of the hinge. Moreover, no degradation in performance was observed at open-close tests conducted 30000 times prior to practical application.

Figure 8 shows the appearance of a notebook PC that utilizes a μHP hinge assembly.

3.3 Heat-sinks Using Fin-composite μHPs

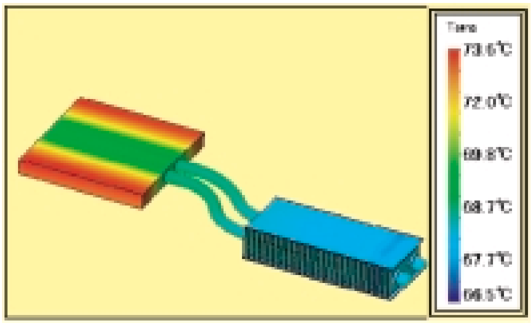
As mentioned earlier, the heat produced by MPU is anticipated to exceed 30 W in the near future. In the meantime, notebook PCs are required to be low in profile and compact in size, reducing the space for heat dissipation. Die-cast fin-composite fans conventionally used for cooling have limitations in terms of the thickness, height, and pitch of the heat dissipating fins since the fins are integrally structured by die casting, so that the fins tend to grow in size to provide sufficient cooling area thus resulting in large sized fans.

Heat-sinks using fin-composite μHP have been devised to overcome such a difficulty. These heat-sinks have a structure such that the heat produced by MPU is conducted to the fin-composite μHP via heat-receiving block, transferred by the μHP to the fins located in front of the draft exit of the housing, and is dissipated externally by the fan thereby effecting forced cooling. Fin-composite μHPs can be structured compact and lightweight since the fin thickness as well as the fin mounting pitch can be



Conditions
μHP: ϕ4 HP x 2
Fan: 45 mm x 45 mm x 10 mm
Frame: ADC12, 3 mm thick
Fin: 15 fins, 1.5 mm thick at 2.5 mm pitch

Figure 9 Result of numerical analysis of die cast-composite fan heat-sink.



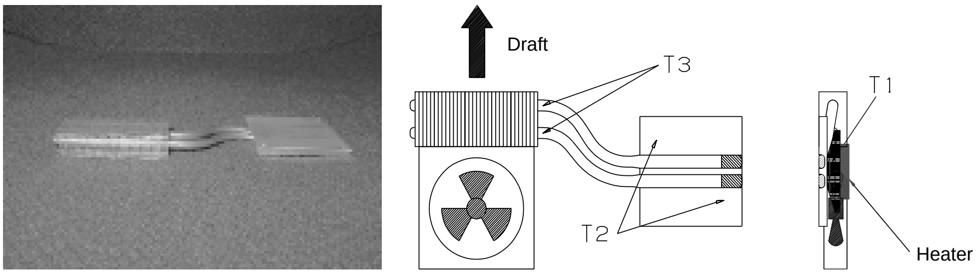
Conditions
μHP: ϕ4 HP x 2
Fan: 45 mm x 45 mm x 10 mm
Block: A6063, 5 mm thick
Fin: A1050, 32 fins, 0.3 mm thick at 1.2 mm pitch

Figure 10 Result of numerical analysis of fin-composite μHP heat-sink.

reduced. Specifically, the fin pitch of fin-composite μHPs can be made as small as 1.2 mm that is less than half of die-cast fin pitch of 2.5 mm, enlarging the heat dissipation area by more than two times. Thus remarkable improvement in performance is anticipated.

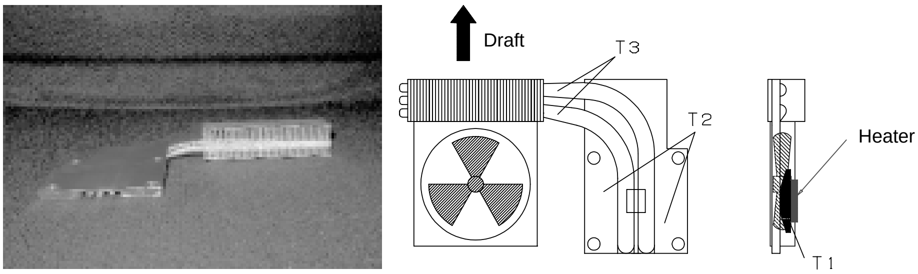
Accordingly, in order to study practical application of fin-composite μHPs, a performance comparison between the heat-sinks using die cast-composite fans and those using fin-composite μHPs was carried out by numerical analysis, assuming the same heat dissipating space. Figures 9 and 10 show the results of the numerical analysis, respectively. It is seen that fin-composite μHP can lower the temperature of MPU by more than 30°C at the heat production of 20 W. Then we proceeded to thermal experiment using a prototype having the same geometry as the model that was subjected to numerical analysis.

Figure 11 shows the appearance of a fin-composite μHP heat-sink with 20 W rating and the schematic of the thermal experiment, and Table 1 summarizes the results. The results of measurement are seen to be in fairly good agreement with those of numerical analysis. The fin-com-



Heater input power (Q): 20 W
Aluminum block heater: 9 mm x 11 mm x 10 mm
Fan: Maximum airflow: 2.5 CFM
Noise level: 24.5 dBA
Revolution: 5000 rpm
Size: 45 mm x 45 mm x 10 mm
Fin: 10 mm x 20 mm x 0.3 mm, 32 fins, P=1.5 mm
Heat pipe ϕ4, L=134 mm, 136 mm

Figure 11 Fin-composite μHP heat-sink with 20 W rating and schematic of thermal experiment.



Heater input power (Q): 29~38 W
Aluminum block heater: 9 mm x 11 mm x 10 mm
Fan: Maximum airflow: 6.0 CFM
Size: 60 mm x 60 mm x 8 mm
Fin: 18 mm x 20 mm x 0.3 mm, 45 fins, P=1.5 mm
Heat pipe ϕ6, L=160 mm, 180 mm

Figure 12 Fin-composite μHP heat-sink --one armed-- with 30 W rating and schematic of thermal experiment.

Table 1 Results of experiment for fin-composite μHP heat-sink with 20 W rating.

Heater input power (Q)	Fan input voltage		T_1 (°C)	T_2 (°C)	T_3 (°C)	T_{air} (°C)	Heat resistance (°C/W)
20 W	3 V	Measured value	77.8	66.6	65.0	35.0	2.14
		ΔT	42.8	31.6	30.0		
20 W	4 V	Measured value	73.9	62.2	60.4	35.0	1.94
		ΔT	38.9	27.2	25.4		
20 W	5 V	Measured value	73.0	60.0	58.2	35.0	1.90
		ΔT	38.0	25.0	23.2		

Notes: 1) Heat resistance = $(T_1\text{-}T_{air}) / Q$
2) $\Delta T = T_i\text{-}T_{air}$

Table 2 Results of experiment for fin-composite μHP heat-sink --one armed-- with 30 W rating.

Heater input power (Q)	Fan input voltage		T_1 (°C)	T_2 (°C)	T_3 (°C)	T_{air} (°C)	Heat resistance (°C/W)
29 W	3 V	Measured value	64.5	53.6	52.7	35.0	1.02
		ΔT	29.5	18.6	17.7		
33 W	4 V	Measured value	68.7	55.9	54.7	35.0	1.02
		ΔT	33.7	20.9	19.7		
38 W	5 V	Measured value	73.6	58.9	57.3	35.0	1.02
		ΔT	38.6	23.9	22.3		

Notes: 1) Heat resistance = $(T_1\text{-}T_{air}) / Q$
2) $\Delta T = T_i\text{-}T_{air}$

posite μHP heat-sink is one of the major candidates for notebook PC heat-sinks of the next generation, and has already been employed in selected notebook PCs.

We are currently developing new fin-composite μHP heat-sinks, one-armed and two-armed, for 30~40 W to cope with increased heat production of MPUs assumable in future. Figure 12 shows the appearance of a one-armed, fin-composite μHP heat-sink with 30 W rating and the schematic of the thermal experiment, and Table 2 summarizes the results. The one-armed heat-sink proved a heat resistance of around 1.0°C/W, demonstrating that MPUs producing 40 W of heat can be dealt with using these heat-sinks.

4. IN CONCLUSION

We have reported on heat-sinks for notebook PCs, focusing on μHP heat-sinks regarded to dominate the field. These μHP heat-sinks have configurations specific to each PC, manifesting the incorporation of design engineers' inventive ideas. This means that the products have been realized by the zeal and efforts of those engineers of PC manufacturers, to whom we wish to express our gratitude.

Hereafter, heat dissipation measures for notebook PCs are expected to grow in importance, so that we intend to standardize the heat-sinks of the third generation introduced in this report, and at the same time, to make efforts to develop new heat-sinks of the next generation.

REFERENCES

1) Kitanoya et al.; Furukawa Electric Review, No.97, 1995. (in Japanese)
2) Hashimoto et al.; Furukawa Electric Review, No.101, 1998. (in Japanese)

Manuscript received on July 23, 2001.