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# Experimental investigation of thermal conduction performance on silicon-based micro flat heat pipe

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**Abstract.** There are several factors that affect heat transfer of heat pipe, for example, structure dimension, filling ratio and vacuum degree of charging. This paper studied the thermal conductivity of micro flat heat pipes (MFHPs) with different structure dimension and with different filling ratio, when the charging vacuum degree of MFHP was decided. When electric power was 2W or 4W, MFHPs with parallel grooves and nonparallel grooves, charged by working fluid with different filling ratio, were carried out. And the filling ratio is 30%, 40% and 50%, respectively. The better thermal performance of MFHP can be evaluated by lower thermal resistance and higher effective thermal conductivity. The experiment results show that MFHP has the highest effective thermal conductivity when the filling ratio is 40%; and the thermal performance of MFHP with nonparallel structure in axial direction is better than that of MFHP with parallel structure.

## Introduction

Micro heat pipe, which is proposed by Cotter et al.[1] for the first time under the background of electronic cooling applications, is mainly used to heat-sink cooling and enhancing heat transfer. Whereafter, many scholars began to research something about micro heat pipe, for example, rectangle and triangle cross section grooves. K. N. Shukla[2] conducted a study on the transport capability of micro heat pipe depended on the vapor continuum limitation ,capillary limitation and the gravity. By using wet anisotropic etching, S. Launay et al. [3] fabricated micro heat pipes of triangular cross-section and with liquid arteries. Compared to silicon, the effective thermal conductivity of micro heat pipe increased sharply. In ref.[4], it was implied that the bent heat pipe is more sensitive to the change of the inclination angle than the straight in terms of the thermal response time and the heat flux of the condenser. Shwinchung Wong et al. [5] performed an experiment on thermal resistance testing to evaluate the thermal performance, and micro heat pipes were charged with water, alcohol and acetone, respectively. Then micro heat pipe charged with water accommodated larger thermal load. A novel study on full visualization and startup

performances of pulsating heat pipe using ammonia as working fluid were experimented in Ref.[6]. Kuan-Ting Lin et al.[7] studied the performance degradation of flattened heat pipes experimentally.
The efficient and rapid heat dissipation has been a problem, because of the sharp increasing of electric device's watt density. With the advantages of good thermal uniformity, high thermal conductivity and the reversibility of heat transfer, heat pipe becomes one of main heat-dissipation device. Compared to traditional heat pipe, micro heat pipe owns smaller dimensions and can transfer heat more efficiently. However, development time of micro heat pipe is so shorter in terms of structure design, technology process and packaging that its thermal performance does not show the best. By now, there are few of studies on micro heat pipe which is applied in heat dissipation of LED device. Therefore, in this paper, the study of micro flat heat pipe for LED device primarily is based on the charging ratio of working fluid.
According to the testing system setup before, as shown in Fig.1, this paper performed the testing study for both parallel and nonparallel structure MFHPs on the filling ratio of working fluid. MFHP with parallel structure has the uniform cross section, while MFHP with nonparallel structure can be divided into two parts and each part has the uniform cross section. Under the condition that input watt is 2W or 4W, the thermal performance of both kinds of MFHPs is evaluated, when the filling ratio is 30%, 40% and 50%.

**Experimental setup and fabrication of MFHP**

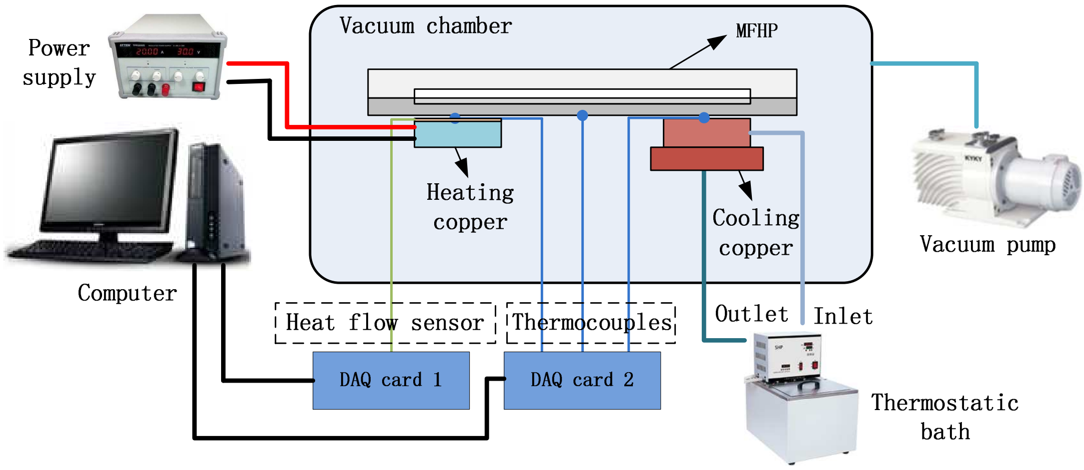



Fig. 1 Schematic diagram of thermal performance testing system for MFHP

**Experimental setup.** The experiment testing system is shown in Fig.1, and the heating source is supplied by heating copper and the output electric power can be adjusted by power supply. There are a heat flow sensor (CAPtec HS-10 with 0.946μv/(W/m$^2$) sensitivity) and a thermocouple (OMEGA TT-K-36 with ±1.05℃ accuracy) fixed between the MFHP and the heating copper, which are used to acquired the heat flux $q$ input to MFHP and the temperature $Te$ of evaporation section of MFHP. In addition, the insulation section and the condensation section of MFHP are installed two thermocouples, and the temperatures are $Ta$ and $Tc$, respectively. In order to reduce the interface thermal resistance, silicon grease (thermal resistance<2K/W) is coated between the surfaces of heat flow sensor and heating copper and between the surfaces of heat flow sensor and evaporation section. In a similar way, between the condensation and the cooling copper is also coated with silicon grease. It is important that the thermal testing experiment is conducted in a vacuum chamber (vacuum degree about 10Pa) to avoid heat transfer by means of convection and radiation.


Fig.2 The photo graph of testing system for MFHP

**Fabrication of MFHP.** In this paper, microgrooves on the n-type silicon (100) wafer were obtained by anisotropic wet etching, and the depth of the microgrooves was about 150 µm. In order to make visualization, the silicon wafer and the Pyrex 7740 with a 200 µm steam chamber were bonded with each other using anodic bonding technique at the temperature of 450 ℃ and voltage of 1200 V[8][9]. The length, width and thickness of MFHP are 45mm, 16mm and 0.5mm, respectively. Internal channel region has length of 35mm, width of 10mm, and thickness of 0.15mm.The detailed dimension of MFHP is shown in Table 1.

Table 1. Structure size of MFHPs

| ID | Shape of channels | width-to-space ratio of channels[µm] | | Depth of channels[µm] | Height of steam chamber [µm] |
|---|---|---|---|---|---|
| NO.1 | parallel | 150/50 | | 150 | 200 |
| NO.2 | non-parallel | 230/70 | 180/120 | 150 | 200 |

The detailed process of the charging of MFHPs is shown in Fig.3. Firstly, MFHPs were pumped until the vacuum degree reached to 3-4Pa, and then cold welding 1 was performed. Secondly, deionized water, as working fluid, was charged into MFHPs with different filling ratio 30%, 40% and 50% by using micro syringe with 1µl accuracy. The charging percentage of working fluid was calculated according to the total internal volume of MFHPs. Finally, cold welding 2 was carried out.

**Results and discussion**

Under the condition that input watt is 2W or 4W, the thermal performance of both kinds of MFHPs is evaluated, when the filling ratio is 30%, 40% and 50%.The effective thermal conductivity can be obtained from Eq.1, which is suggested by Y.J. Youn et al.[10][11].

$$K_{eff} = \frac{Q \times L_{eff}}{A_c \times (T_e - T_c)}. \tag{1}$$

Where $Q$ is the input watt; $Leff$ is the effective length of MFHP; $Ac$ is the cross section of MFHP; $Te$ and $Tc$ represent the temperatures of evaporation section and condensation section of MFHP, respectively.

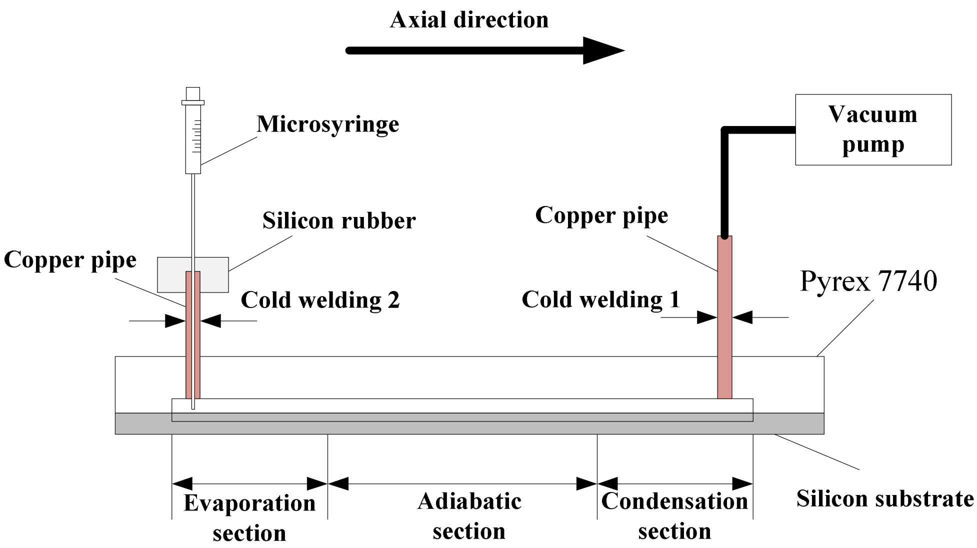



Fig. 3 Schematic diagram of charging system

$$L_{eff} = \frac{L_e + L_c}{2} + L_a \tag{2}$$

Where $L_e$ and $L_c$ are the length of evaporation and condensation, respectively, and $L_a$ means the length of adiabatic section.

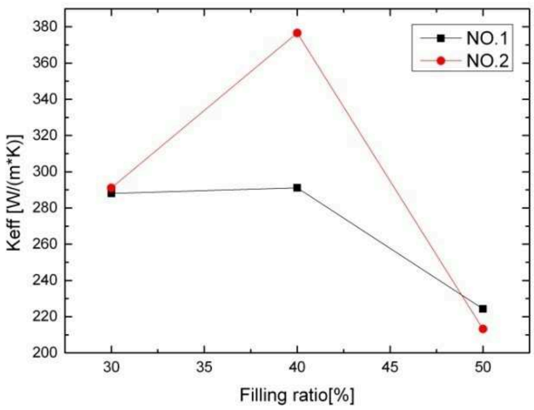



Fig. 4 Effective thermal conductivity with different filling ratio when input watt is 2W

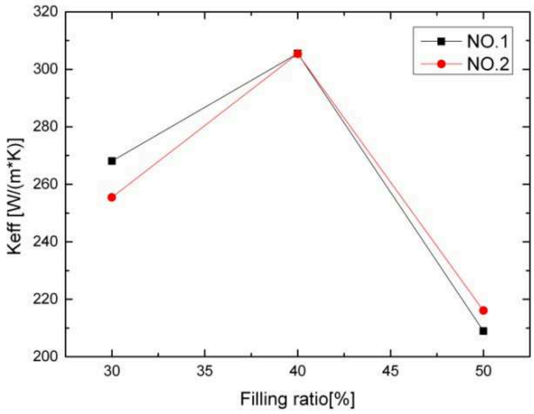
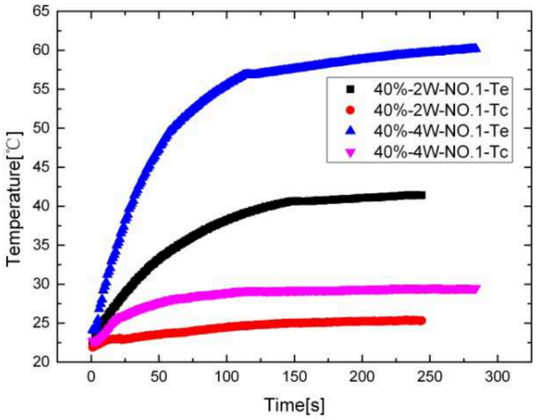



Fig. 5 Effective thermal conductivity with different filling ratio when input watt is 4W

As can be seen from Fig. 4, when filling ratio is 30% or 50%, the effective thermal conductivities of both parallel and nonparallel MFHP, numbered as *NO.1* and *NO.2* respectively, have no significant difference. And the effective thermal conductivity of *NO.1* MFHP is 290W/(m·K) while *NO.2* MFHP is 220 W/(m·K). When filling ratio is equal to 40%, *NO.2* MFHP has the highest effective thermal conductivity with the value of 360 W/(m·K). However, the effective thermal conductivity has almost no changes, when filling ratios are 30% and 40%.

When input watt is changed to 4W, the difference of the effective thermal conductivities of the two structure MFHPs is very small, as shown in Fig.5. When filling ratio is 30%, the effective thermal conductivity of *NO.1* MFHP is slightly larger than that of *NO.2* MFHP. When filling ratio is 40%, the effective thermal conductivities of both MFHPs are equal to each other. When filling ratio increases to 50%, the effective thermal conductivity of *NO.1* MFHP is a little less than that of *NO.2* MFHP.



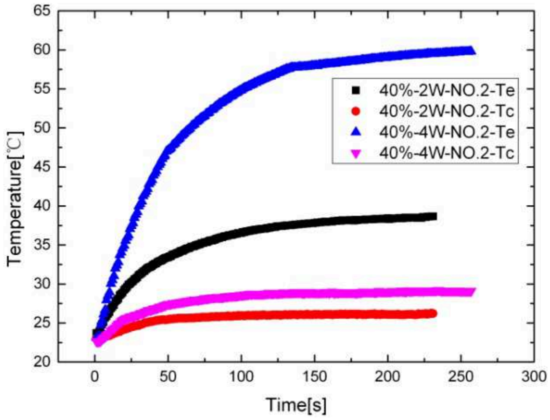
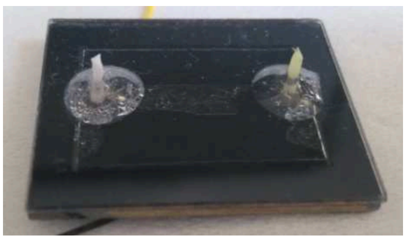




Fig.6 Temperature changing curve of NO.1 MFHP under different input watt

Fig.7 Temperature changing curve of NO.2 MFHP under different input watt

In Fig.6 and Fig.7, when reaching to a steady state of heat transfer, both *NO.1* and *NO.2* have similar steady temperature curves when input watt is 4W. If the input watt is 2W, the steady temperature of *NO.2* is slightly lower than that of *NO.1* in evaporation section.

The results of testing experiment imply that the thermal performance of nonparallel structure MFHP is much better. Especially, when filling ratio is 40%, the effective thermal conductivity of nonparallel MFHP is larger than that of parallel MFHP about 90 W/(m·K). This is because that there is no dryout phenomenon happened in evaporation section so that vapor can return to condensation section and condense effectively; In the mean time, nonparallel structure can strengthen the capillarity and promotes working fluid returning to evaporation section quickly. To some extent, the efficiency of phase change heat transfer increases sharply. However, an obvious decline of the heat transfer of both kinds of MFHPs appears when filling ratio is 50% and the thermal resistance reaches to above 14K/W. The reason is that too much working fluid in MFHP results in that part of vapor and liquid cannot participate in phase change, which is negative to efficient heat transfer.



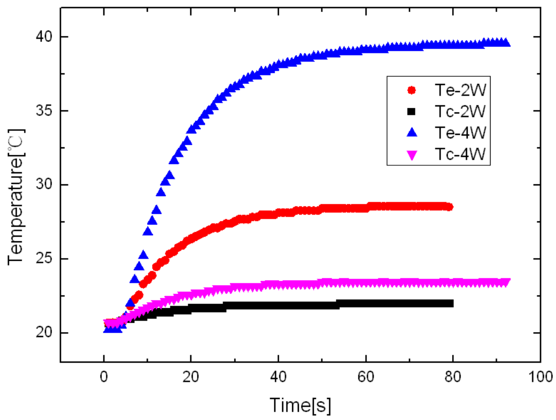



Fig.8 Graph of MFHP with the dimension of 20mm*26mm

Fig.9 Temperature changing curve of evaporation and condensation sections

This paper also studied the thermal performance of smaller MFHP, which has only the length of 26mm, the width of 20mm, and thickness of 1.5mm. It is called SMFHP in this paper, and the width-to-space ratio of channels is 150[μm]/50[μm]. As show in Fig.8, the phase change area of the MFHP is 20mm*13.5mm, and the inner height is 0.3mm. In order to make a comparison with two kinds of MFHPs mentioned above, SMFHP also be charged into 40% of working fluid.

According to Fig.6, Fig.7 and Fig.9, whether input power is 2W or 4W, SMFHP can reach a steady status. It is obvious that the temperatures of SMFHP on evaporation and condensation are much lower than that of both kinds of MFHPs above. The temperatures of evaporation are lower about 20℃ and 10-15℃, respectively, when input power is 2W and 4W; while the temperatures of condensation are lower about 2℃ and 4℃, respectively. The experiment result implies that shorter length of MFHP in axis direction can accelerate phase change by decreasing the distance of flowing. In the process of heat transfer, vapor can travel to condensation quickly and liquid can also flow back to evaporation immediately.

## Conclusions

Under the condition of different filling ratio, the heat transfer test of MFHPs with nonparallel structure and parallel structure were conducted. When the filling ratio is 40%, effective phase change cycle in MFHP can be formed, and the biggest effective thermal conductivity can be obtained. Meanwhile, the nonparallel grooves can promote capillarity and accelerate heat transfer of phase change, which results in that the temperature difference between evaporation section and condensation section is very small. Under similar condition, SMFHP shows better with smaller temperature difference and higher effective thermal conductivity.

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