International Journal of Heat and Mass Transfer 53 (2010) 2377–2384

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

A novel vapor chamber and its performance

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ARTICLE INFO

Article history:
Received 24 September 2009
Received in revised form 24 September 2009
Accepted 18 December 2009
Available online 19 February 2010

Keywords:
Vapor chamber
Heat pipe
Flat-plate heat pipe
Evaporation resistance
Condensation resistance

ABSTRACT

The performance of a novel vapor chamber is tested in this study. In this vapor chamber, parallel grooves are made on the inner surface of the top plate, with inter-groove openings, to replace the conventional porous wick. To the inner surface of the bottom plate is sintered a layer of porous wick as the evaporator. The peaks of the groove walls directly contact with the wick so that the grooves function as vapor path, condenser and structural supporters simultaneously. The corrugated groove walls provide not only an enlarged condensation area, but also a direct shortcut for a portion of the liquid condensed on the groove surface to be absorbed back to the wick. Thus, smaller liquid-flow resistance and hence high anti-dryout capability are achieved. The test module includes a copper plate-fin heat sink in combination with a top fan. In this study, the evaporator wick was made of sintered multi-layer copper screens and the footprint of the vapor chamber was 10 cm × 8.9 cm. With a 2.1 cm × 2.1 cm or a 1.1 cm × 1.1 cm heating area, the vapor chamber resistances were measured for heat load increasing from 80 W to beyond 300 W. Good performances with low vapor chamber resistance and large heat load limit were obtained under different orientations. In addition, the individual evaporation resistances and condensation resistances were measured for representative conditions. The evaporation resistance was the dominating part of the vapor chamber resistance. Both the evaporation resistance and the condensation resistance decreased with increasing heat load, except that the evaporation resistance increased after the occurrence of partial dryout.

1. Introduction

With increasing heat dissipation of electronic chips, the cooling problem becomes more and more challenging. The high-capacity vapor chamber has found applications in high-power chips, such as GPUs and server's CPUs. The vapor chamber is a flat-plate heat pipe with excellent heat dissipation ability due to its uniform temperature distribution and large condensation area. Combined with heat sink fins, it leads to more uniform fin temperature and, hence, more effective cooling. With its flat surface, a vapor chamber is ready for direct contact (via thermal interface material) with the CPU. Advantages of the vapor chamber and its applications in electronics cooling have been described in Mochizuki et al. [1]. Similar to a heat pipe, a vapor chamber is a two-phase heat transfer device. The inner wick on the bottom wall in contact with the CPU serves as the evaporator, where the working liquid evaporates and carries away the heat in form of latent heat. The upper wall functions as the condenser where the water vapor condenses and releases the latent heat, which is dissipated out through the adjacent heat sink. The condensed water is then recycled back to the evaporator by the capillary force. While the sintered-powder wick provides strong capillary attraction in the evaporator, it also yields serious frictional drag for the recycling liquid. At a high-power situation, the liquid may not be recycled quickly enough so that the evaporator dries out, leading to excessively high temperature.

Agata et al. [2] applied the vapor chamber in notebook computers. With a 2 cm × 2 cm heating area, their vapor chamber resistance was about 0.15 K/W. Wu et al. [3] applied their low-profile vapor chamber for cooling high-density blade servers. These vapor chambers adopted the conventional design with its inner surface fully covered with sintered copper powder wick. The container material was copper and working fluid was DI water.

Different designs of vapor chamber have been proposed. Take et al. [4] fabricated roll bond aluminum vapor chamber used as the heat spreader for notebook computers. The internal groove corners were used as the capillary structure for liquid transport. The working fluid was R-134a or R-123. However, thermal resistance performance data of their vapor chamber were not available. Cao and Gao [5] fabricated wickless network vapor chambers made of either aluminum or copper. Go [6] adopted aluminum container with etched-metal micro-structure wick. The working fluid was acetone. With a 2 cm × 2 cm heater, their lowest vapor chamber resistance was about 0.24 K/W at a heat load of 140 W.

In the work of Grubb [7], limited performance test data are available for the Therma-Base™ vapor chamber of Thermacore Inc. The Therma-Base™ also has a conventional structure with its inner surface fully covered with sintered copper powder wick and supporting

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doi:10.1016/j.ijheatmasstransfer.2010.02.001

studs used as stiffeners. A 2 cm × 2 cm dummy heater was applied at the central bottom and the chamber top was connected with a heat sink with a contact area of 9.3 cm × 6.7 cm. The heat sink footprint was 10.4 cm × 7.8 cm. The vapor chamber resistance decreased from 0.6 to 0.35 K/W as the heat load increased from 100 to 300 W. Lee et al. [8] adopted a boiling-enhanced multi-wick structure in their vapor chamber (no detailed description). With a 2.5 cm × 2.5 cm heater and a heat sink footprint of 9.0 cm × 8.8 cm, the vapor chamber resistance could be as low as 0.04−0.03 K/W for heat loads of 100–330 W.

In this work, a novel design of vapor chamber is proposed and tested. With a simple and efficient design, it not only can be easily manufactured with low cost, but also yields excellent anti-dryout characteristics. The performance tests verify its low thermal resistance close to the best data in the literature.

2. The novel vapor chamber

Fig. 1 illustrates our novel design of vapor chamber, in comparison with a conventional one. The major difference is the replacement of the conventional wick-laid upper wall with a parallel-grooved plate, having inter-groove openings for vapor dispersion. The peaks of the groove walls directly contact with the wick so that the grooves function as vapor path and the groove walls as stiffeners. The upper corner of each groove provides capillary effects to facilitate transport of the condensed liquid along the grooves. In conventional vapor chambers, support studs are needed to prevent distortion by inward compression, as shown in Fig. 1a. This change leads to a number of advantages: (1) its simple structure is easy for manufacturing and cost-effective; (2) the liquid-flow resistance is much smaller in parallel grooves than in conventional porous wick on the upper surface; (3) part of the condensed water can be directly absorbed by the evaporator wick, without traveling through a long loop as in the conventional design; (4) the groove walls provide anti-compression strength without extra support studs; (5) the grooves function as both condenser and vapor path, reducing vapor chamber thickness; (6) a larger condensation area is gained with the corrugated groove walls; (7) with the upper plate pressing the wick, the wire-mesh wick may not be sintered onto the lower plate. This is suitable for heat-spreading applications without strict requirement of low thermal resistance. Greatly simplified manufacturing process and reduced cost could be achieved. The second and third advantages result in an excellent anti-dryout feature. Given specified wick permeability, a larger heat load limit can be attained; given a requirement of heat load limit, a thinner wick can be used. The fourth advantage is useful in thinning the container wall of the vapor chamber. Advantages (2)–(5) altogether make possible the fabrication of vapor chambers as thin as 1.0–1.5 mm. The wick can be selected from wire mesh, sintered powders or their combinations. The performance of a vapor chamber is closely related to the wick type, wick thickness and the amount of working fluid. In this study, we present the test results for multi-layer copper wire-mesh wicks.

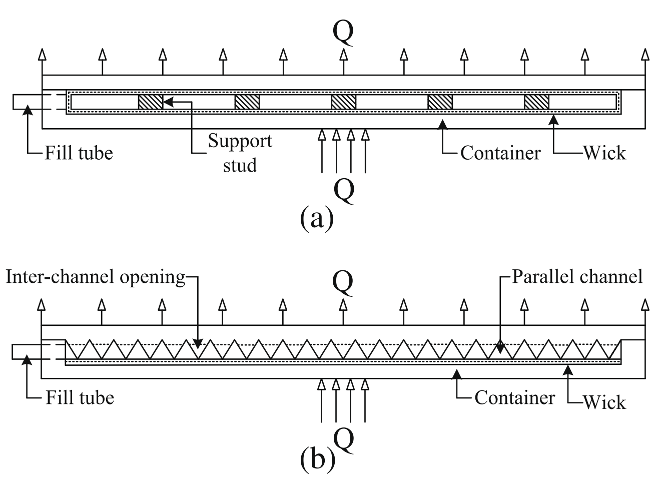

Fig. 1. Comparison of (a) conventional and (b) present vapor chambers.

For repetitive tests, the vapor chamber is sealed with o-rings. The test sample is shown in Fig. 2. A thicker bottom plate is used to accommodate the o-rings and fill tube. To eliminate the excessive heat spreading in the thicker bottom plate, a trench loop is made around the heated area to reduce the plate thickness to 1 mm.

3. Experimental methods

The experimental setup is shown in Fig. 3. The vapor chamber interior had an area of 10.0 cm × 8.0 cm. The container was made of oxygenless copper and the working fluid is degassed deionized water. The heated surface was located on the central bottom of the vapor chamber. On the top surface of the vapor chamber was mounted a skived copper plate-fin heat sink, 10 cm long and 8.9 cm wide. There were 56 fins, each 3.5 cm high, 0.03 cm thick and 10 cm long, with a fin spacing of 0.13 cm. A fan of 9 cm × 9 cm × 2.5 cm blew downward at a power of 5 W. The inlet air temperature ranged from 25 to 28 °C. A set of K-type thermocouples were embedded at selected locations in the heat sink base for temperature measurement. The specific positions and numbers of these measuring points are described in Fig. 4. A data logger having a resolution of 0.1 K was used to record the thermocouple readings. The arithmetic mean of the seven temperatures was taken as the average temperature of the heat sink base. Thermal interface material (TIM), Dow Corning TC-5021, $k = 3.3$ W/m K was laid between the heating surface and the vapor chamber and between the vapor chamber and the heat sink base. The heating surface is the top of a 2 cm × 2 cm square copper column whose seat was heated with cartridge heaters. The heating power was controlled by a regulated DC power supply. Except for the heating surface, the copper column was enclosed in a bakelite box stuffed with ceramic insulation material. Three 36-gauge fine K-type thermocouples measured the copper column temperatures from which the heat loads were calculated. According to the linearity of the temperature readings and the comparison with the output of the DC power supply, the uncertainty of the heat load measurements was found less than 7%. To reduce the contact resistance, a pressure of about 20 N/cm^2 was exerted between the heating surface and the bottom of the vapor chamber.

Before wick sintering, the wire screens and the bottom plate were consecutively cleaned in an ultrasonic cleaning tank with detergent and acetone, before thorough water rinsing. Sintering was performed in a 900 °C hydrogen/nitrogen atmosphere for 2 h. During sintering, the screens and the copper plate were clamped with a fixed pressure. Soon afterwards, the vapor chamber was assembled and sealed by clamping. A selected amount of degassed deionized water was filled into the vapor chamber right

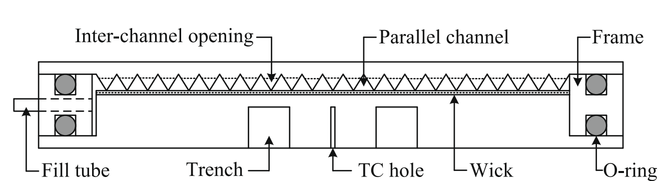

Fig. 2. The modified vapor chamber for repetitive tests.