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Micro and miniature heat pipes – Electronic component coolers

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Abstract

The time of beginning of heat pipe science was near 40 years ago with first heat pipe definition and prediction of most simple cases. Micro and miniature heat pipes have received considerable attention in the past decade. The interest stems from the possibility of achieving the extremely high heat fluxes near 1000 W/cm^2, needed for future generation electronics cooling application. Now at the computer age some changes of basic equations are performed, more powerful predicting methods are available with increasing awareness of the complexity of heat pipes and new heat pipe generations. But even today heat pipes are still not completely understood and solution strategies still contain significant simplifications. Micro and miniature heat pipes have some additional complications due to its small size. A short review on the micro and miniature heat pipes is presented.

Keywords: Micro heat pipes; Miniature heat pipes; Heat transfer; Phase change; Evaporation; Condensation; Confined space

1. Introduction

Micro (MHP) and miniature heat pipes (mHP) [1] are small scale devices that are used to cool microelectronic chips. Microchannels in MHP are fluid flow channels with small hydraulic diameters. The hydraulic diameter of MHPs is on the order of 10–500 μm, the hydraulic diameter of mHPs is on the order 2–4 mm. Smaller channels application is desirable because of two reasons: (i) higher heat transfer coefficient, and (ii) higher heat transfer surface area per unit flow volume. Actually new cooling techniques are being attempted to dissipate fluxes in electronic components in order of 100 up to 1000 W/cm^2. Recently high-performance miniature heat pipe panels were designed and manufactured in the Luikov Institute, Belarus, Fig. 1.

Besides electronic cooling, there are many other applications, where MHPs may be useful. For example, MHPs are interesting to be used in implanted neural stimulators, sensors and pumps, electronic wrist watches, active transponders, self-powered temperature displays, temperature warning systems.

MHPs are promising to cool and heat some biological micro-objects. So there is a real necessity to improve heat pipe parameters. In heat pipes basic phenomena and equations are related with liquid–vapor interface, heat transport between the outside and the interface (“radial” heat transfer), vapor flow and liquid flow. There is a strong interaction between basic phenomena in heat pipes, Fig. 2. Feedbacks may cause instabilities, such as waves, flooding, performance jumps. Following Busse [2] basic equations are related to vapor flow in the MHP channel, liquid flow in the capillary structure, interface position between the vapor and liquid (mechanical equilibrium yields interface curvature K), radial heat transfer, vapor flow limit, capillary limit. MHPs and mHPs are sensitive to the surplus liquid inside. Surplus liquid tends to be accumulated at the wet point defined by $K = K_{\min}$. Sometimes the wet point is disposed not at the end of the heat pipe and there could be deterioration of the radial heat transfer coefficient. Interface instability is the reason of the liquid accumulation in the condenser and leads to dry-out spots arrival in the evaporator. While traditionally heat pipe

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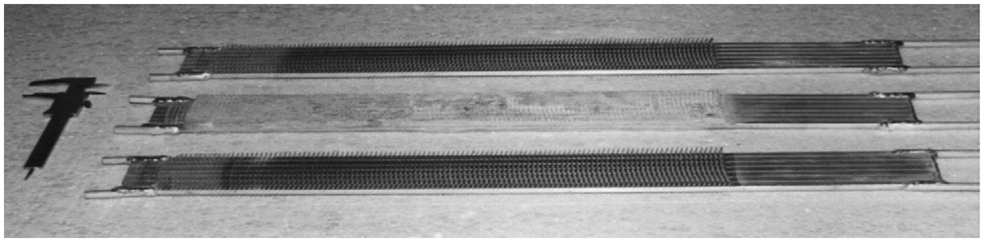

Fig. 1. Flat aluminium heat pipe panels for semiconductor component cooling.

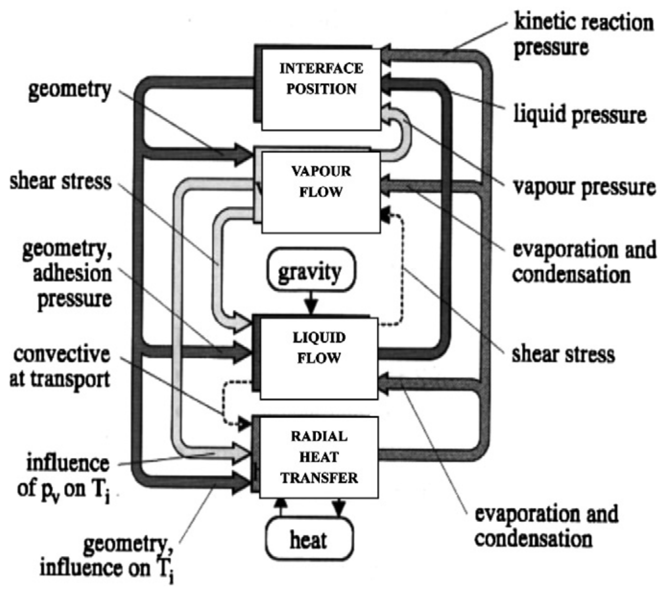

Fig. 2. Interaction between basic phenomena in heat pipes.

condenser resistance is seemed small and often neglected in MHP/mHP the detailed tests revealed substantial temperature drop across the length of the condenser. Potential sources of this temperature drop may be non-condensable gases, the surplus liquid and constrained vapor space. The resulting change of the vapor stress on the interface tends to increase the deformation of the interface.

2. Micro heat pipes

Micro heat pipe phenomena is often available in nature. For example, there is an analogy between micro heat pipe operation and functioning of a sweat gland [3]. Open-type mini/micro heat pipes are suggested in [4,5], as a system of thermal control of biological objects and drying technology. Some theoretical models capable to predict the effects of the thin film region on the evaporating and condensing heat transfer have been developed, particularly for triangular and trapezoidal-grooved MHPs, in order to determine the maximum evaporation heat transfer through the thin film region [9–11]. The detailed theoretical analysis of capillary flow, the heat transfer in the condenser, evaporator and macro region (Fig. 3) is presented in [10,12]. In all above mentioned references related to MHP 1D theoretical analysis is available with emphasizes on one microchannel hydrodynamic and heat transfer: Most of investigators focus on the capillary heat transport capability because the fundamental phenomena that govern the operation of MHPs, arise from the difference in the capillary pressure across the liquid–vapor interface in the evaporator and condenser zones. The experimental data on silicon micro heat pipe arrays filled with methanol or water were published in [11]. Recently a review paper on MHP/mHP for the cooling of electronic devices was published in [12]. Some new MHP designs are presented in the literature mostly related with an increasing of the surface of the evaporation and condensation and vapor pressure drops decreasing in the vapor channels (heat pipe spreaders, flat plate micro heat pipes, etc.) [13]. Analysis of the applicability of different grooved MHPs shows, that there are some advantages of this heat pipe design (simple geometry of the microchannel, low cost of fabrication, using etching technology in silicon chip) and drawbacks such as sensitivity to the presence of non-condensable gases in the vapor channel, the strong liquid–vapor interfacial shear stress,

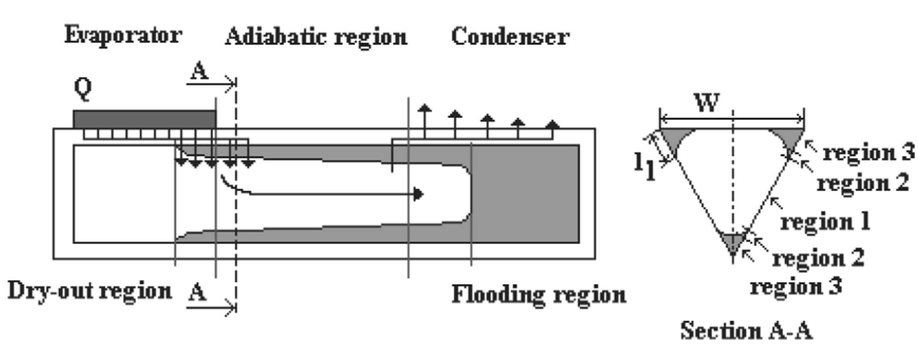

Fig. 3. Micro heat pipe with triangular capillary microchannels [12].