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ENHANCEMENT OF HEAT TRANSFER IN POOL BOILING WITH ALUMINUM CHIPS USING ETCHING PROCESS

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ABSTRACT

Pool boiling is the process in which the heating surface is submerged in a large body of stagnant liquid. The relative motion between the vapor produced and the surrounding liquid is near the heating surface is due to primarily to the buoyancy effect of the vapor. As the time goes by during boiling due to the formation of the film on the heating surface heat transfer reduces. Therefore, enhancement of heat transfer on micro surfaces is required. This is achieved by doing surface modification and fabrication technologies. The fabrication techniques for achieving these surfaces, which are technically classified into machining, etching, coating, chemical process, and micro systems are describes. Out of all, these methods in this work heat transfer is enhanced by increasing the flow moment of vapor bubbles on the surface. This can be achieved by increasing surface area by using etching techniques. In etching process certain proportion of acid mixture is used, so that the surface made uneven. Hence there is no chance of formation of unstable film on the surface. The objective of this work is to evaluate the pool boiling performance structured surface features on an aluminum chip. The performance is compared with the normal chip before etching. It has wide range of electronic cooling applications because if it's high potential for removing large amounts of heat resulting from the latent heat of evaporation. It is observed that after etching the heat transfer is enhanced by 15.96%. It is also observed that pure aluminum did not enhances the heat transfer even by etching, but the aluminum alloy enhances the heat transfer after etching.

Key words: Pool boiling, Heat transfer enhancement, Surface modification, Etching.

INTRODUCTION

Boiling represents the change of phase from liquid to the vapor. There is no change in temperature during boiling i.e., the saturated liquid and the saturated vapor exist at the same temperature. Pool boiling means the all the layers of the liquid exist at the same

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temperature. Entire liquid boils as one pool. It refers to the natural convection. During pool boiling, the latent heat involved during phase change from liquid to the vapor phase becomes significant. The increase in heat transfer coefficient allows pool boiling to be used in wide range of applications. As the process does not require any moving parts the method is cost effective. During critical heat flux condition, which leads to increase in wall temperature, causes the metal to failure. Therefore, mechanisms and behavior of bubble nucleation, growth as well as rewetting of surface is of great interest. Many researches had gone to enhance the heat transfer in pool boiling. It was found that the onset of nucleation over active cavities is a function of sub cooling, pressure and the length of thermal boundary layer. Since the heat transfer in pool boiling is associated with the contact of surface, therefore, surface modification to the heater surface is expected to directly affect the heat transfer phenomena. In recent years, many researches focused on surface enhancement to promote bubble nucleation and increased heat transfer.[1]

Different types of surfaces like fins, micro pin surfaces, and silicon chips are used to increase the heat transfer and found that micro structures effectively increase the heat transfer compared with the smooth surface.[2] In boiling process, the bubble nucleation is very important because at the higher temperatures the formation of bubbles is very high. Hence at these temperatures the one bubble combines with other bubble to form a film on the surface thereby decrease the heat transfer. Therefore, researches had gone to reduce the formation of film on the surface and it was found that the film formation depends on bubble departure diameter. If surface is modified in such a way that the bubble departures diameters are different then heat transfer enhances. Some studies have found that the formation of micro channels on the heater surface increases the heat transfer.[3] They observed a pattern of oscillations for the vapor slug in the top and bottom channels due to the evaporation of the liquid and rewetting of the heated surface.[4]

Other researchers have focused on enhancing the boiling by creating the cavities on the surface by using various methods and concluded that the contact angles have dependence on surface roughness, and vapor cutback phenomenon is responsible for the initiation of critical heat flux.[5] It was concluded that an increase in pressure will decrease the effects of surface roughness during boiling. The objective of this project is to enhance the heat transfer in boiling by surface modification, which in turn is modified by using etching process. When heat is added to a liquid from a submerged solid surface which is at a temperature higher than the saturation temperature of the liquid, it is usual for a part of the liquid to change phase. This change of phase is called boiling. Boiling is of various types, the type depending upon the temperature difference between the surface and the liquid.

Boiling is one of the most efficient modes of heat transfer. Due to its high efficiency, boiling heat transfer has been widely used in industries and the cooling devices such as CPUs and LED chips.[7] However, the recent rapid increase of power consumption in electronic packages including highly integrated circuits causes the major issue of the cooling. The heat flux is very concentrated, and it is difficult to cool down the temperature in time. Moreover, the cooling flow passages in the small thermal device are usually mini, and the generating bubbles by boiling of the normal working fluids are usually large in size when compared with the size of the flow passage, yielding high pressure drop or unstable flow due to the flow blockage by the vapor bubbles. So the bubble size of the working fluid needs to be sufficiently small for the application of boiling to small thermal devices.

Theoretical analysis

The rate of heat transfer process depends on the surface area, which varies with the hydraulic diameter of the pore.

Table 1:

Chip	Type	Depth (μm)	Notch
A	Plain	0	No
B	Etched	3.0685	No

The main advantage of this etched surface is large wetted area i.e, large surface area for heat transfer in small space, which leads to a very high heat transfer rate.

The critical heat flux $q_c = \frac{Qc}{A} = \frac{V \times I}{A}$

Peak heat flux in saturated pool boiling is given by –

$$\left(\frac{q}{A}\right)_{max} = \frac{\lambda\pi}{24}\left[\sigma g\,(L-\nu)^{1/4}\,(\nu)^{1/2}\left(1+\frac{\nu}{L}\right)^{1/2}\right]$$

Depth of the pore can be estimated by using following equation

$d = 16.2\text{-}16.2e^{-0.021t} \quad t < 200$

d = Depth of the etch in microns (micro meters);

t = Time of etch in seconds

EXPERIMENTAL

Materials and methods

Aluminum etching

In this work, aluminum alloy (consists of silicon) taken as substrate. It is polished in such a way that to make the surface uniform. Then the polished surface is taken to the disk type polisher. Then the substrate is etched by using Keller's reagent. Keller's reagent consists of HCl, HF, HNO_3 and H_2O. The HF present in the Kellers reagent reacts with the silicon in the metal and forms hexasilicate and precipitates, thereby etching take place. Therefore, the silicon is removed from its lattice sites and forms cavities. Due to this formed cavities the surface area will increase and thereby heat transfer will enhance. Further, there is no chance of formation of unstable film on the surface. Typical aluminum etchants contain mixtures of 2.5 mL HNO_3 (for Aluminum oxidation), 1.5 mL HCl (to dissolve the Al_2O_3), 1 mL HF (for wetting and buffering) and H_2O dilution to define the etch rate at given temperature. Aluminum etching is highly exothermic, an under etching of the resist mask causes local heating (increased etch rate) and super-proportional under etching, if no agitation is performed. Strong H_2-bubbling reduces etch homogeneity. Improvements of the etch rate homogeneity can be achieved if the etching will be interrupted every approximate 30 seconds by a short dip into deionization water. Hereby, the H_2 bubbles temporarily vanish. Generally, etching starts after the dissolution of few nm Al_2O_3 film present on every aluminum surface.

The alkaline developers dissolve the Al_2O_3 where the resist is primarily through developed (at regions with lower resist film thickness, near the edges of cleared structures, or below cleared structures with larger features). Dependent on the extent of (desired or undesired) over-developing as well as delay between development and Al-etching, the process parameters may lead to a spatial in homogeneous aluminum etching start. The aluminum etch rate of HNO_3 mixtures strongly depends on the temperature and doubles for every 5°C. The luminum etchant has the following composition: HF: HCl: HNO_3: H_2O: 1%: 1.5%: 2.5%:95%.

Process of aluminum etching

Prepare the specimen using pure aluminum metal Bakelite powder solution specimen leveler. Grind the specimen in linsher to make it flat to expose the fresh metal surfaces and polish specimen on series of emery papers rotate the specimen properly. Polish specimen using a disc polishing machine whose disc in covered with velvet cloth wetted with Al_2O_3 abrasive. Then add etchant to mark grains by grain boundaries. Inspect the surface of specimen for its suitable.

Table 1:

Material & method	Composition
Aluminum solution	Al-95%, Al_2O_3-95%
Heat treatment	No
Etchant	2.5% HNO_3
Keller's reagent	1.5%HCl, 1.0% HF
Distilled water	95%
Etchant time	10-15 sec

Analyze the micro structure under microscope and capture the microscope structure of specimen using image analyzing system. The process of grinding and polishing the specimen should be held properly, so that flat surface is obtained. During polishing on emery papers, the specimens rotated uniform angle. Order of polishing on emery papers should be followed by i.e, 1/0, 2/00, 3/0, 4/0. Optimum etching time (10 sec in this case) should be maintained for proper etching takes place.

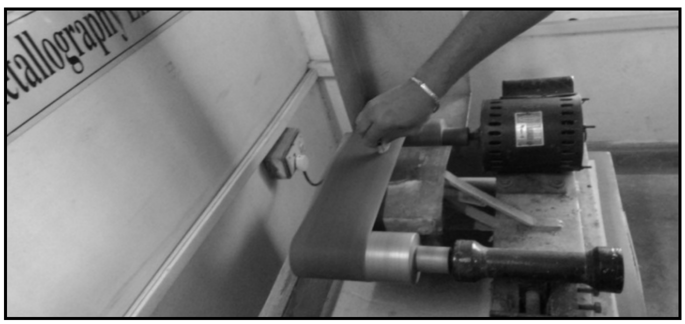

Fig. 1: Metallographic linsher for flattening the surface of aluminum

Fig. 2: Series of polishing stands

Fig. 3: Disc polishing to remove the coatings on the metal surface

Fig. 4: Microscope to observe the structure of the substrate

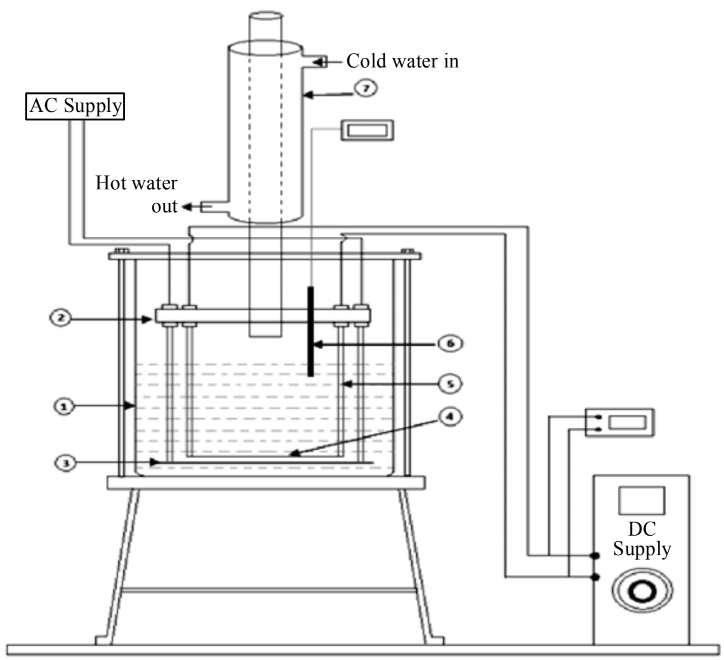

Fig. 5: Experimental setup for pool boiling

Experimental procedure without etching

Fill up the container with distilled water such that both the heaters are completely submerged. The water heating coil is switched on. Once the required bulk temperature of water is reached, the heater is switched off. By slowly varying the variable position, the boiling phenomenon is observed. Carefully note down the voltage and also current at that point. Where the wire breaks, the procedure is repeated for different value of bulk temperatures. Keep the zero voltage position before starting the experiments. Take sufficient amount of distilled water in the container so that both the heaters are completely immersed. Connect the test heater wire across the studs tightly. After the attainment of critical heat flux condition decrease slowly the voltage and bring it to zero.

Table 2: Observations through pool boiling without etching

S. No.	Bulk temp. (^{o}C)	Excess temp. difference (ΔT)	Ammeter reading (Amp)	Voltmeter reading (Volts)	Heat flux (*q*), W/m^2
1	30	0	0.2	30	6
2	34	4	0.4	35	14
3	40	10	0.6	40	24
4	44	14	0.8	45	36
5	50	20	1	50	50
6	56	26	1.2	55	66
7	61	31	1.4	60	84
8	68	38	1.6	65	104
9	76	46	0.6	70	42
10	82	52	0.4	75	30

Experimental procedure with etching

Here, we did same experiment, except changing the area of the specimen when compare to previous experiment. Area of specimen can increase through etching process by using Keller's reagent, we can etch the specimen. Using metallographic linsher we can make the surface uniform. Polish the specimen on a series of Emery papers 1/0, 2/0, 3/0, and 4/0 and rotate the specimen properly. It is polished on each Emery paper for duration of 15 min. Switch on the disk polishing machine so that as the discs are rotating spill the abrasive solution on the velvet cloth. Wash the specimen with water to remove further coatings on the surface. Add the etchant to the surface so that pores are formed on the surface. Then dry the specimen of a specific duration of time. Inclined metallurgical microscope used to find the microstructure on the specimen. After doing these all steps, the specimen is to be fitted in the experiment of heat transfer in pool boiling. Then we observe the following results.

Table 3: Observations through pool boiling with etching

S. No.	Bulk temp. (^oC)	Excess temp. difference (ΔT)	Ammeter reading (Amp)	Voltmeter reading (Volts)	Heat flux (q), W/m^2
1	30	0	0.3	30	9
2	34	4	0.6	35	21
3	40	10	0.7	40	28
4	44	14	0.9	45	40.5
5	50	20	1.2	50	60
6	56	26	1.4	55	77
7	61	31	1.8	60	108
8	68	38	1.9	65	123.5
9	76	46	1.6	70	112
10	82	52	1.2	75	90

RESULTS AND DISCUSSION

Comparison of pool boiling curves for a metal chip before and after etching process is shown in Fig. 6.

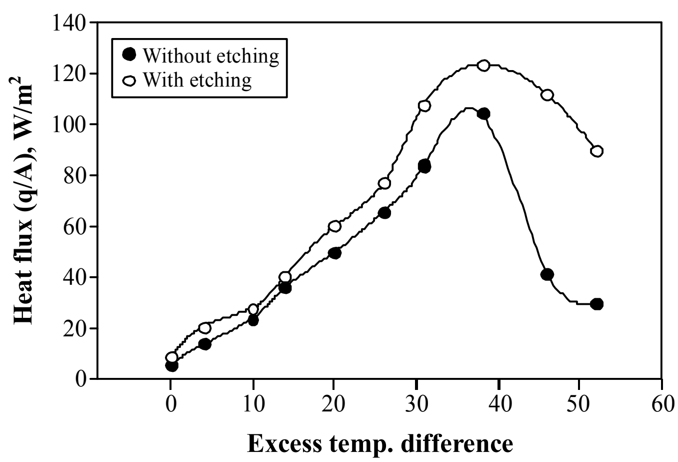

Fig. 6: Heat flux through pool boiling with and without etching

From the above graph, it is observed that before etching the maximum heat flux that can be achieved is 104 W/m^2. After etching the maximum heat flux that can be achieved is 123.5 W/m^2. Therefore, the percentage increase in heat flux after etching is 15.96%.

CONCLUSION

- Etching process increases the surface area of the metal thereby heat transfer enhances.
- Due to the formation of pores, further there is no chance of formation of unstable film on the surface.
- Percentage increase in heat transfer after etching process is 15.96%.
- Comparing to other techniques like using fins, this method has advantage that economically low. Therefore, by using etching process heat transfer enhances in the metal chip.

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