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DEVELOPMENT OF THERMAL SWITCH USING LIQUID COLUMN

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ABSTRACT

This paper presents the thermal switch which is composed of several switching channels, breathing grooves, reservoirs and actuators to control the liquid column. In the “on” state, a switching channel is filled with liquid supplied by an actuator, which decreases the thermal resistance. In the “off” state, the air fills in the gap of two plates instead of the liquid column and the thermal resistance is increased. Through this switch operation, temperature of the designated hot spot can be controlled locally. In order to realize the desired switch operation, the liquid column should be precisely controlled based on channel design. The switching channel is composed of burst area and path area to achieve the smooth operation. The burst area was geometrically designed to provide the hydrophilic surface geometrically by taking into account of burst area. Experiments were performed on a designed switch for the liquid column control and the heat flow regulation. The results showed that this thermal switch is able to make the “on” and “off” state by controlling liquid column well. Also, the temperature distribution and thermal resistance has been changed according to channel state.

INTRODUCTION

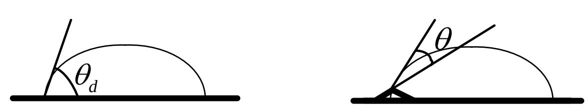
In recent years there has been strongly interested in heat regulation in various area. For instance, spindle system, heat management of electronic device, micro-engine, optical system, etc [1, 2, 3, 4]. Therefore, high performance thermal switches have been focused in various areas as a device can control the heat flow between two surfaces [5].

In this study, thermal switch which is operated by the switching channel formation is proposed to regulate the local heat, and is realized through fabrication. A heat switch panel with seven switches is investigated. On demand, each channel is filled with liquid supplied by an actuator, forming liquid column. Each liquid column can be operated independently and the result is the local heat flow control.

EFFECT OF SURFACE GEOMETRY

The precise liquid control should be provided to realize the stable switch operation. Since relatively large scale liquid columns are used, the contact angle is dominant factor of on operation. To provide the appropriate contact angle, the switch channel geometries and the surface treatment with chemicals are adapted to incorporate with various surface conditions.

Fig. 1 illustrates the effect of solid surface configuration. Fig. 1.(a) shows the droplet which reaches critical contact angle and Figure 1.(b) represents change of contact angle of the same droplet on the triangular shaped surface. The contact angle of the Fig. 1.(b)(latter) becomes smaller and more stable than in the Fig. 1.(a) (former). Therefore, the hydrophilic or hydrophobic property can be achieved using geometry of a substrate as designed, which provides good wetness or separation of a liquid at the target surface during the switch operation. Using this effect, the thermal switch can be realized.



θ_d : *Dynamic contact angle* θ : *Contact angle*

(a) Dynamic Contact angle (b) Geometry effect

Figure 1 Contact angle

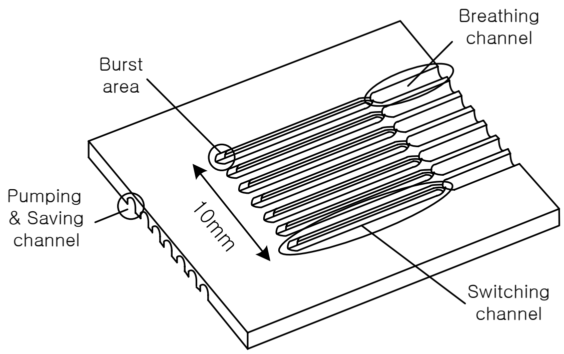


Figure 2 Liquid column thermal switch

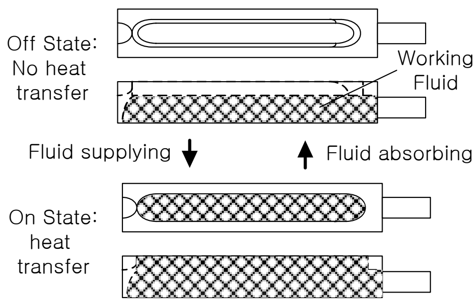


Figure 3 Operation principle

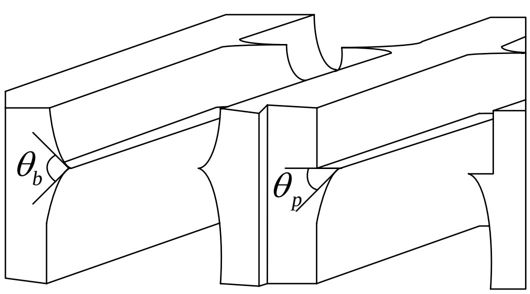


Figure 4 Cross section of burst area

OPERATION PRINCIPLE AND DESIGN OF THERMAL SWITCH

In the Fig. 2, overall configuration of the proposed thermal switch panel is shown. Several switching conduction channels are provided on the top surface, and the reservoir and pumping channels are provided on the bottom surface corresponding position with the conduction channels. The channel size was determined to neglect the gravity effect.

Fig.3 illustrates the switch operation process. First, the switch on state, the working fluid supplied through the pumping channel fills the switching channel without any vacancy (on state). And then working fluid is absorbed and the liquid column is disappeared in the switching channel (off state).

To achieve the distinct switch operation, two conditions should be satisfied. First, the burst pressure, which varies with the contact angle and prevents the fluid moving into the switching channel, should be lower than middle parts of the conduction channel at the starting point of the switching channel in order to generate liquid column without any vacancy. The flow is in the direction of the lowest burst pressure when it is supplied. If the burst pressure of other parts is low than the start point of the switching channel, that will be a initial point of the liquid column generation. At that case, the air will be remained inside of the channel due to the fluid barrier. It affects to heat transfer efficiency due to the conductivity of air is lower than liquid. Thus, the switch channel design should consider the burst pressure as a factor for liquid column control. The burst area, which has high angle compared with other parts of the switching channel (Fig.4), should be located on the end of the switching channel in order to satisfy this condition. The fluid moves into the conduction channel first at the burst area due to the channel geometry.

Second, the working fluid in the channel of the switch should be clearly removed during the 'off' operation. To achieve this, the hydrophilic chemical was coated onto the reservoir to provide high adhesive force. The coating surface should make a low contact angle and be maintained in the water for a long time.

RESULTS

The switching operation of the fabricated switch is shown in Fig. 5. The 'on' and 'off' processes were tested using water with a small amount of a red dye to observe the flow clearly. The dark part of the switch shows the reservoir channel coated with the hydrophilic chemical. In the 'off' state, the reservoir channel was filled only with water (Fig. 5a). The switching channel was filled with water supplied from the pumping channel (Fig. 5b). When the switching channel was full of water, the 'on' state is activated (Fig. 5c). To attain the 'off' state, the water was absorbed through the pumping channel and the air supplied through the breathing channel filled the switching channel in place of the working fluid (Fig. 5d). In this way, the switch was operated successfully.

The temperature distribution and the overall thermal resistance were measured by changing number of 'on' state channels from zero to seven in order to characterize the proposed thermal switch. The temperature of the operated channel becomes lower than that of the other parts in the 'off' state. This indicates that the local temperature distribution can be regulated by the operation of the switch (Fig. 6). Measurements of the overall thermal resistance are presented in Fig. 7. The average temperatures of the top side and the bottom side of the thermal switch were obtained using a thermocouple and an IR camera, respectively. The overall thermal resistance linearly decreases with the increment of the 'on' state channel.

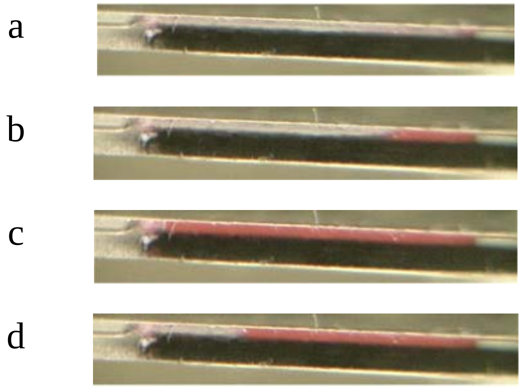


Figure 5 Liquid column control
(a) Initial state(off state)
(b) Fluid supplied
(c) Liquid column(on state)
(d) Fluid absorbed

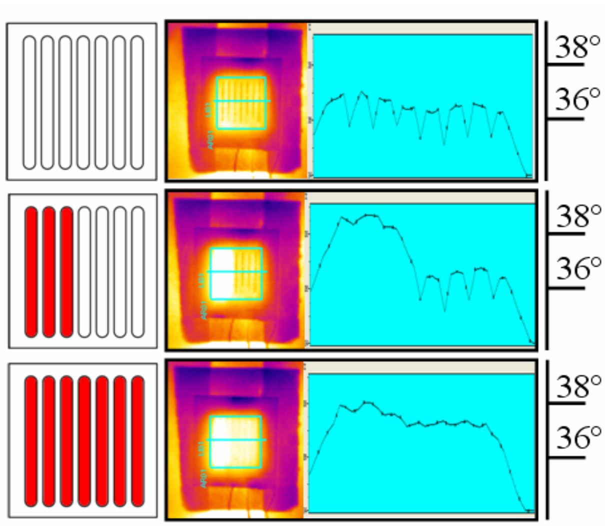


Figure 6 Thermal experiment result

CONCLUSION

The development of thermal switch using liquid column for the control of the heat flow is presented in this paper.

To enhance the operation of switch via a liquid channel, the design strategy focused on the geometrical configuration of the switch channel, which affects the contact angle and the burst pressure. The stable switching operation was confirmed using the channel geometry and the hydrophilic coating.

The heat transfer is controlled by the proposed switch. The temperature distribution and the overall thermal resistance were regulated with changing the number of ‘on’ state channels. Consequently, the thermal resistance and temperature distribution can be controlled by the proposed thermal switch.

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