ӘОЖ : 628.149 DOI 10.53002/113

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Variable thermal interfaces based on discrete liquid droplets

We propose a variable thermal interface based on an array of discrete liquid droplets initially confined on hydrophilic islands in the substrate. The droplets are reversibly morphologically transferred to a continuous liquid film when mechanically compressed by the opposite substrate to create a heat-conducting pathway with low thermal resistance. We study the criterion of reversible transition in terms of hydrophilic sample size and liquid volume. The dependence of fluid morphology and rupture distance on the diameter and District share of hydrophilic Islands, fluid volume, as well as load pressure are also characterized from a theoretical and experimental point of view. The thermal resistance in the state is characterized experimentally for ionic liquids, which are promising for practical use due to the insignificant vapor pressure. A service life test unit has been designed to assess the reliability of the interface under continuous switching conditions at relatively high switching frequencies.

Keywords: variable thermal interface, reversibility, liquid morphology, thermal resistance, reliability.

Introduction

Interchangeable thermal interfaces allow controlled modulation of the thermal conductivity between the devices of interest and their heat sinks/sources. They are key components of Micro Devices and systems that require reconfigurable heat transfer pathways to control and control low-power heat. Potential applications [1,2,3,4] include microbolometers with locally adjustable dynamic ranges, pulsed thermoelectric cooling, solid-state electrocaloric refrigerators requiring a fast thermal cycle of the working environment, pyroelectric waste heat collection, and satellite heat management.

It is well proven that thermal transfer through solid-solid contacts is often limited to surface dead ends that reduce specific contact areas. Previous experimental studies have shown that even for rough silicon surfaces on a nanometer scale (<10-4 m2·K·w), a significant load pressure (Order 1 MPA) is required to achieve a small thermal contact resistance (<10-4 m2·K·W) [1]. This may be due to trapped gas layers, which strongly inhibit thermal conductivity. Dense arrays of vertically aligned carbon nanotubes [5] or nanofibers [6] have received much attention for potential heat transfer applications. A relatively large load pressure, however, was often necessary to achieve a small thermal resistance, as only a small part of the tubes communicated with the opposite surface. In addition, the strong adhesion between carbon nanotubes and the opposite surface [7] during close contacts and the resulting delamination defects render them unsuitable as alternating thermal interfaces.

The previous study showed an appropriate thermal switch consisting of an array of discrete Mercury droplets [2]. Since the thermal conductivity of mercury is relatively high, the thermal resistance in each drop can be very low (~4 × 10-6 M2·K·W). However, Mercury poses a threat to health and the environment. Some alternative room temperature liquid metals can bypass this problem, but they oxidize quickly in the surrounding air, making their practical use difficult.

A recent study has repeatedly demonstrated the potential of an alternative liquid-mediated thermal interface that can provide thermal contact resistance comparable to direct solid-state contacts at a small load pressure [8]. The main idea was to use the predominance of surface tension over gravity and other volumetric forces in micromasses to reversibly change the morphology of parallel columns of dielectric fluid bounded on microchannels. In its out-of-state state, the two interface-defining surfaces are separated from each other by an air or vacuum gap. The fluid is bounded by an array of discrete microchannels separated from each other by hydrophobic regions. The two surfaces are then in contact to compress and deform the liquid columns until a continuous liquid layer is formed. Two pages are pulled apart to disable the interface. The continuous liquid layer is then first transformed into an array of liquid bridges covering the gap, which then break off to break the thermal bond between the two surfaces.

The channel-based liquid thermal interface has the advantages that it can be easily made using standard microfabrication methods, and each channel can be easily filled with a specific amount of liquid to control the final distance.

The main disadvantage of this design, however, is associated with its requirement for a long mechanical stroke. The distance required for the rupture of liquid Bridges is equal to the length of the microchannels, or usually ~1 mm. This can be a problem in applications that require micro actuators in a limited starting range or a fast thermal cycle.

This work informs our theoretical and experimental work on an alternative design that replaces microchannels with arrays of discrete chemical expression hydrophilic islands to reduce or otherwise control the breaking distance of a liquid bridge. As an illustration, Figure 1 shows the difference in the break distance between the two constructions. For one fluid volume in question, the interface with circular islands has a break distance of less than 300 microns [Figure 1(a)], while the interface with parallel microchannels is more than 700 microns [Figure 1(B)].

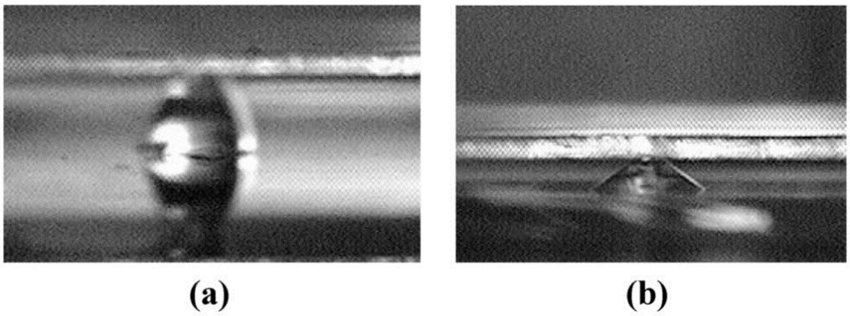
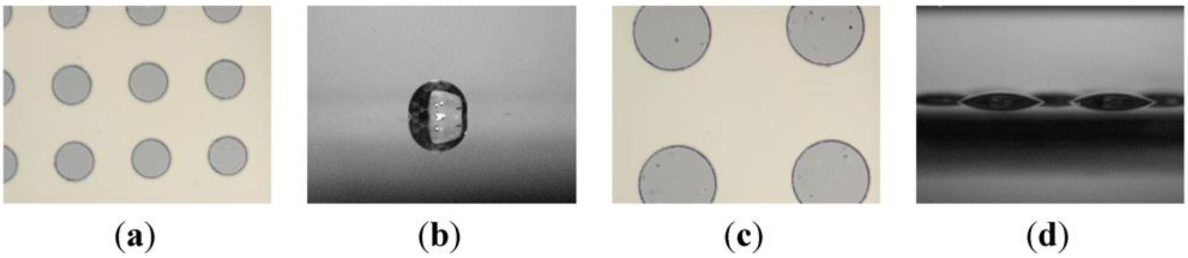


Figure 1. comparison of the breaking distances of liquid bridges defined by (a) microcannals and (b) discrete hydrophilic samples.

Metodology

One of the most important design issues for interchangeable thermal interfaces is their reversibility. That is, the continuous liquid shell resulting from the deformation and fusion of an array of discrete liquid droplets must return to the original state of discrete droplets when the two surfaces are separated from each other.

As a model system, we consider a set of circular hydrophilic patches on a non-hydrophobic surface. The two main design parameters are: (1) sample size, characterized by diameter d, and (2) the territorial portion of the pattern, defined as the proportion of surface area occupied by hydrophilic Islands F. when d or f is too small, the continuous liquid film formed in the addition state can become one large liquid drop instead of several discrete droplet arrays, as shown in Figure 2.



Сурет 2. Үлкен және кіші өрнектерді салыстыру. Кішірек гидрофильді үлгілері бар субстраттағы сұйықтық (a) жарылғаннан кейін бір тамшыға айналады, бірақ үлкенірек гидрофильді үлгілері бар субстратта (c) дискретті тамшылар (d) түзеді.

To establish numerical reversibility criteria, we compare the interface energy of the Es of a single-drop State and the EM of a discrete multi-drop State. Assuming that the effect of gravity is negligible, we can bring liquid drops closer as cut balls. The interfacial energy can then be written as:

$$E_s = \left[2\pi r^2 \frac{1-\cos\theta_2}{\sin^2\theta_2} - \cos\theta_1 \cdot \pi r^2 \cdot f - \cos\theta_2 \cdot \pi r^2 \cdot (1-f)\right] \cdot \gamma_{lv} \quad (1)$$

$$E_m = f\left[2\,\frac{1-\cos\alpha}{\sin^2\alpha} - \cos\theta_1\right] \cdot \gamma_{lv} \cdot \frac{V}{g} \quad (2)$$

$$V = \frac{\pi r^3}{3}\frac{(1-\cos\theta_2)^2}{\sin^3\theta_2}(2+\cos\theta_2) \quad (3)$$

Here r is the radius of the wetting zone of a single droplet determined by the total volume (equation(3)), the apparent contact angle of a discrete droplet in each hydrophilic sample, g is the required minimum gap (i.e. the target minimum thickness of a continuous liquid layer), and V is the total volume of the liquid.

Figure 3 shows the interfacial energy calculated for two states f = 0.2, V = 0.7 μL and g = 20 μm. We consider a situation where the contact angle in the hydrophilic pattern is θ1 = 24.4° (experimentally measured for Silicon after plasma etching of the hydrophobic coating) and θ2 in the hydrophobic zone (e.g. Teflon® coating) is 120°. It is believed that the liquid-vapor surface tension γlv = 73 mn/M is comparable to water.

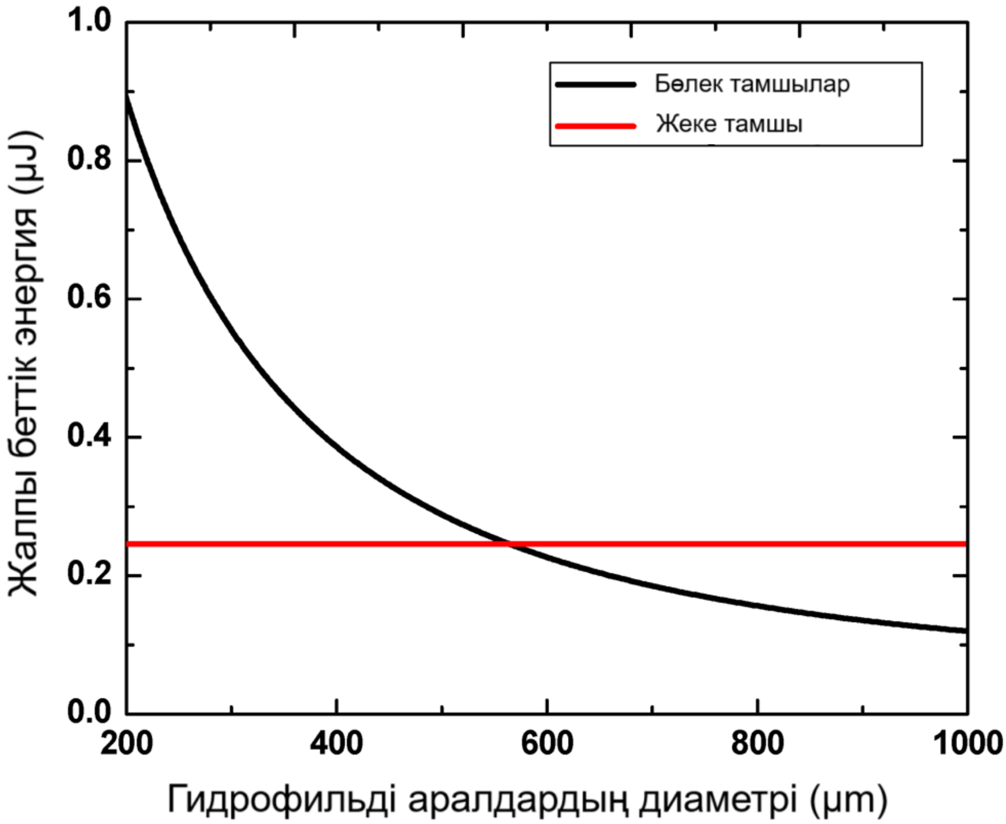


Figure 3. interface energy versus sample size of one drop State and multi-drop State

Research results

When the sample size is below about 560 microns, the discrete multi-drop State has a higher energy and is therefore less energetically favorable than the single-drop State. That is, instead of forming several discrete droplets, a continuous liquid layer can turn into one large liquid drop when two surfaces are separated from each other. To achieve reversibility, the sample size must exceed this value.

Figure 4 (A) shows the difference in the interfacial energies of the two states for different values of the areal part of the expression F. X-segments of about 500 to 700 microns correspond to the minimum sample size required for a discrete multi-drop state to be energetically acceptable. This minimum sample size decreases as f increases. In other words, smaller samples can achieve reversibility in higher sample fractions, since neighboring hydrophilic samples are located close to each other. When the sample size is very large, the interfacial energy difference decreases as the pattern density increases. The liquid droplets in these large specimens tend to merge to form one large drop. As shown in Figure 4 (b), smaller visible angles are needed to prevent neighboring liquid droplets from merging in higher sample fractions.

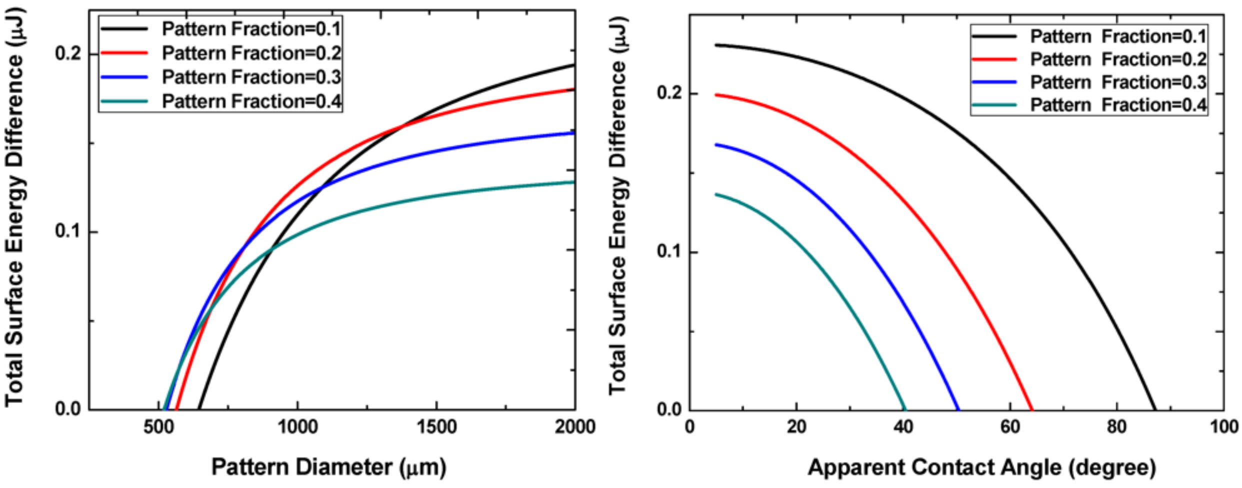


Figure 4.the difference in interface energy (B) with different sample sizes and densities (a) or different visible angles of discrete droplets.

Conclusion

This work establishes the concept of alternating thermal interfaces based on an array of discrete liquid droplets initially confined on hydrophilic islands in a hydrophobic substrate. The droplets are reversibly morphologically transferred to a continuous liquid film when mechanically compressed by the opposite substrate to create a heat-conducting pathway with low thermal resistance. We study the criterion of reversible transition in terms of hydrophilic sample size and liquid volume. The dependence of fluid morphology and rupture distance on the diameter and District share of hydrophilic Islands, fluid volume, as well as load pressure are also characterized from a theoretical and experimental point of view. The thermal resistance in the state is characterized experimentally for ionic liquids, which are promising for practical use due to the insignificant vapor pressure. In order to assess the reliability of the interface in the case of continuous switching at relatively high switching frequencies, a service life test unit is designed.

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Ж.А. Жунусов

Дискретті сұйықтық тамшыларына негізделген айнымалы жылу интерфейстері

Біз бастапқыда субстраттағы гидрофильді аралдармен шектелген дискретті сұйықтық тамшыларының массивіне негізделген айнымалы жылу интерфейсін ұсынамыз. Тамшылар қайтымды морфологиялық жолмен қарама-қарсы субстратпен механикалық сығымдалған кезде үздіксіз сұйық қабықшаға ауысады, жылу өткізгіштігі төмен жылу өткізгіш жол жасайды. Біз гидрофильді үлгінің мөлшері мен сұйықтық көлемі бойынша қайтымды ауысу критерийін зерттейміз. Сұйықтық морфологиясы мен жарылу қашықтығының гидрофильді Аралдардың диаметрі мен Аудан үлесіне, сұйықтық көлеміне, сондай-ақ жүктеме қысымына тәуелділігі теориялық және эксперименттік тұрғыдан да сипатталады. Күйдегі жылу кедергісі будың шамалы қысымына байланысты практикалық қолдануға перспективалы иондық сұйықтықтар үшін эксперименталды түрде сипатталады. Салыстырмалы түрде жоғары коммутациялық жиіліктерде үздіксіз коммутация жағдайында интерфейстің сенімділігін бағалау үшін қызмет ету мерзімін тексеру блогы жасалған.

Түйінді сөздер: ауыспалы жылу интерфейсі, қайтымдылық, сұйықтық морфологиясы, жылу кедергісі, сенімділік.

Ж.А. Жунусов

Изменяемые тепловые интерфейсы на основе дискретных капель жидкости

Мы предлагаем изменяемый термоинтерфейс, основанный на наборе отдельных капель жидкости, изначально удерживаемых на гидрофильных островках в подложке. Капли обратимым образом преобразуются в сплошную пленку жидкости при механическом сжатии противоположной подложкой для создания теплопроводящего канала с низким тепловым сопротивлением. Мы изучаем критерий обратимого перехода с точки зрения размера гидрофильного образца и объема жидкости. Зависимость морфологии жидкости и расстояния разрыва от диаметра и доли участков гидрофильных островков, объема жидкости, а также давления нагрузки также охарактеризованы с теоретической и экспериментальной точек зрения. Термическое сопротивление в этом состоянии экспериментально охарактеризовано для ионных жидкостей, которые перспективны для практического использования из-за незначительного давления паров. Для оценки надежности интерфейса в условиях непрерывного переключения при относительно высоких частотах переключения была разработана установка для проверки срока службы.

Ключевые слова: изменяемый тепловой интерфейс, обратимость, морфология жидкости, термостойкость, надежность.

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