A REVIEW ON ACTIVE TECHNIQUES IN MICROCHANNEL HEAT SINK FOR MINIATURIZATION PROBLEM IN ELECTRONIC INDUSTRY

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Highlights
The present article provides a brief overview of all the active techniques that has been incorporated in microchannel heat sink.

Abstract
With continuous miniaturization of modern electronic components, the need of better cooling devices also keeps on increasing. The improper thermal management of these devices not only hampers the efficiency but can also cause permanent damage. Among various techniques, microchannel heat sink has shown most favourable performance. To further enhance the performance, two techniques i.e., active and passive are used. In passive technique, no external power source is required like heat sink design alteration and working fluid modification. External power source is necessary for heat transfer augmentation in the microchannel heat sink when using the active approach. Due to compact size of microchannel, active techniques are not used more often. However, the present work highlights the different active technique used in microchannel i.e., Electrostatic forces, flow pulsation, magnetic field, acoustic effects, and vibration active techniques. Above mentioned techniques have been analysed in detail.

Keywords
microchannel heat sink; active technique; electrostatic forces; flow pulsation; magnetic field; heat transfer enhancement.

Introduction

With rapid growth in technology, electronic devices are getting smaller day by day. According to Moore's law, the number of transistors on various electronic devices doubled every two years as depicted in Figure 1 (a) and will also follow same trend in near future [1]. Factors responsible for this drastic increase in transistors packing density are reduced size of single transistors, increased chip area and improved design. Li et al. [2] in 2019 proposes 2D transistors which will replace 3D transistors and will further increase packing density. As electric current flowing through any electronic component is always accompanied with some heat dissipation. So, there is drastic increase in heat flux for such devices. If this heat flux is not managed properly, it will lead to degraded

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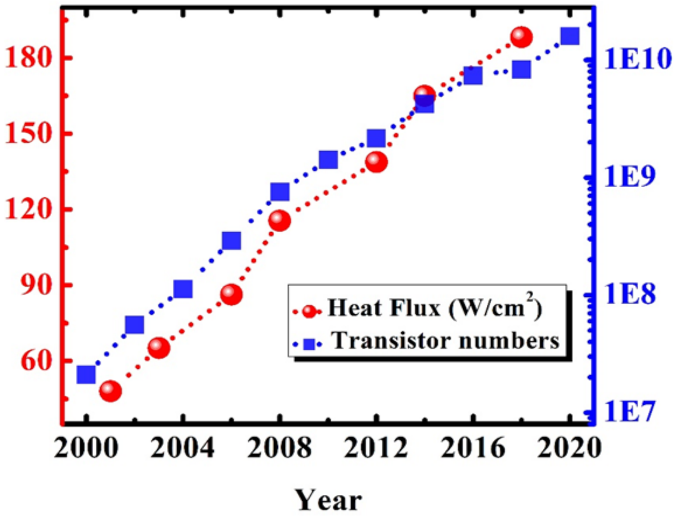
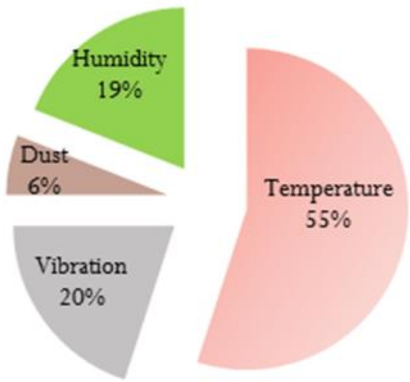
performance or efficiency. Moreover, if problem persists for longer time, it can also damage the device. Pedram and Nazarian [3] found major reason for failure of electronic (VLSI) circuits is improper thermal management as illustrated in Figure 1(b). Heat flux dissipation from such compact devices is not possible through conventional cooling methods like natural or forced cooling (by fan or fins). Also, these methods are loud and bulky.



(a)



(b)

Figure. 1 (a) Variation of heat flux and number of transistors in various devices over the year,
(b) Factor responsible for electronic components failure

Compared to air, thermal conductivity of liquid is much more and can yield four to ten times better heat transfer rate. Using liquid cooling, researchers have focuses on various emerging techniques to encounter the high heat flux dissipation. Among several emerging techniques i.e., micro heat pipe, jet impingement, spray cooling, carbon nanotube, thermoelectric and microchannel [4], microchannel heat sinks have received most attention by research fraternity due to many favourable characteristics. Microchannel are generally fluid flow channels having dimensions lesser than 1 mm. However, there is no consensus on range of hydraulic diameter and on flow transition state for microchannel fluid flow. Higher convective surface area, smaller coolant inventory, quick response time, reduced space, and material costs are some of the advantages of microchannel heat sinks. In addition to electronic devices, microchannel heat sink can also be helpful for high heat producing devices like turbine blades, fusion reactor blankets, rocket engine, hybrid vehicle, hydrogen storage, thermal control in microgravity, etc.[5].

Different techniques opted for heat transfer enhancement

Tuckermann and Pease [6] have performed pioneering work on microchannels by utilizing it in electronic cooling. With a maximum substrate temperature rise of 71°C, they were able to dissipate heat flux of 7.9 MW/m^2. Since then, other techniques have been used to boost the heat transmission rate even more. Figure 2 depicts the several methods used to improve heat transfer in microchannel heat sinks.

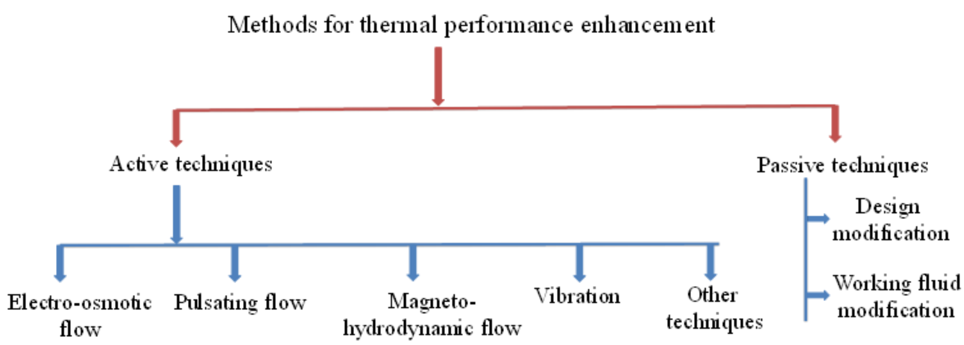


Figure 2. Different methods opted for heat transfer enhancement in microchannel heat sink.

Passive techniques

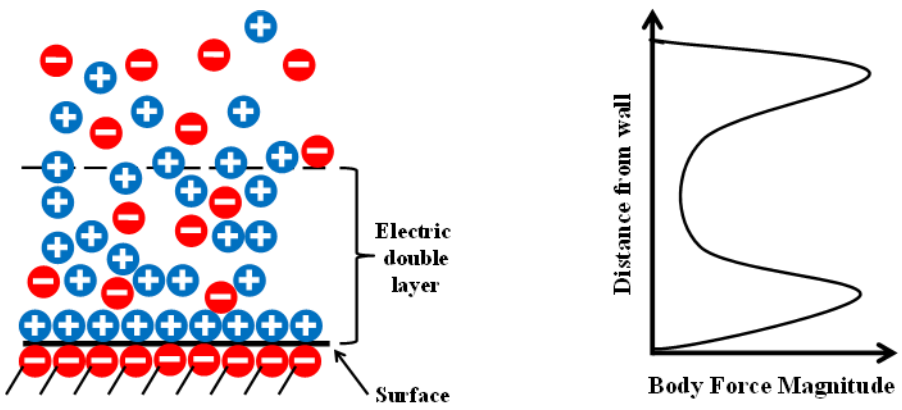
Passive procedures are those that do not necessitate the use of any energy. Because there are no moving parts, this method is more cost-effective and dependable. Design and working fluid variations are two passive approaches used in microchannel heat sinks. In design modification, researchers have opted different channel cross sections, waviness, vortex generators, tip clearance, inlet and outlet arrangement, pin fin configuration [7–9] for thermal augmentation. While in fluid modification, several types of additives like nano particles, phase change material, are used to enhance the working fluid's thermal conductivity [10]. Use of latent heat of working fluid has also shown better performance but still is in developing phase for microchannel [11]. The vortices flow formation, redevelopment of boundary layers, flow mixing, and entrance effects are mechanism affected by the passive techniques.

Active techniques.

Active techniques are those techniques which uses external power source or energy for performance augmentation in microchannel heat sink. The major reason for using either active techniques or passive technique is to disrupt the flow, secondary flow generation, and out of plane fluid mixing. Comparing to passive techniques, active techniques have not been used more often in microchannel due to its compact size. Mainly three different approaches have been used by researchers, i.e., electrostatic forces, flow pulsation and vibration. These techniques are explained in detail below.

Electrostatic forces.

Most studies on microchannel heat sink (MCHS) are focused on pressure driven flow, while use of electro osmotic flow (EOF) is less considered. Electro-osmosis works based on surface charge of the microchannel. The channel walls gain a surface charge when it encounters an electrolytic solution [12]. As the solution flows through the channel, the counter ions in the solution get accumulated in the vicinity of channel wall. An electrical double layer is created near the wall as shown in Figure 3(a). Furthermore, with application of external electric field, the fluid in EDL experiences a body force which causes fluid near to the wall to either move along or in direction opposite to the electric field. The magnitude of body force depends upon charge density and electric field strength and its variation with wall distance is shown in Figure 3(b). Fluid momentum from thin EDL is then transferred to bulk fluid by viscous stresses. EOF has shown positive effect on performance enhancement [13–15]. Using Poisson–Boltzmann equation and the Navier–Stokes equations, Morini et al. [16] numerically studies EOF in MCHS having rectangular and trapezoidal cross sections.



(a) (b)

Figure 3. (a) Schematic diagram of Electric double layer near channel wall, (b) Variation of Body forces with wall distances.

Han et al. [17] evaluate the heat transfer performance of pure electro-osmotic flow (EOF), pure pressure driven flow (PDF), and combination flow (CF) using numerical simulations i.e., PDF + EOF in trapezoidal MCHS using COMSOL. They observe notable augmentation in fluid motion with the aid of EOF, particularly in microchannel having smaller hydraulic diameter. Influence of electric potential on Nusselt number and thermal resistance for different pressure drop was not so significant as seen in Figure 4. However, it is comparatively more noticeable at lower pressure driven flow. It was observed that with change in electric potential from 1 to 6 kV/cm, there is increment of 21.87% and 12.05% in Nusselt number for 5 kPa/cm and 15 kPa/cm.

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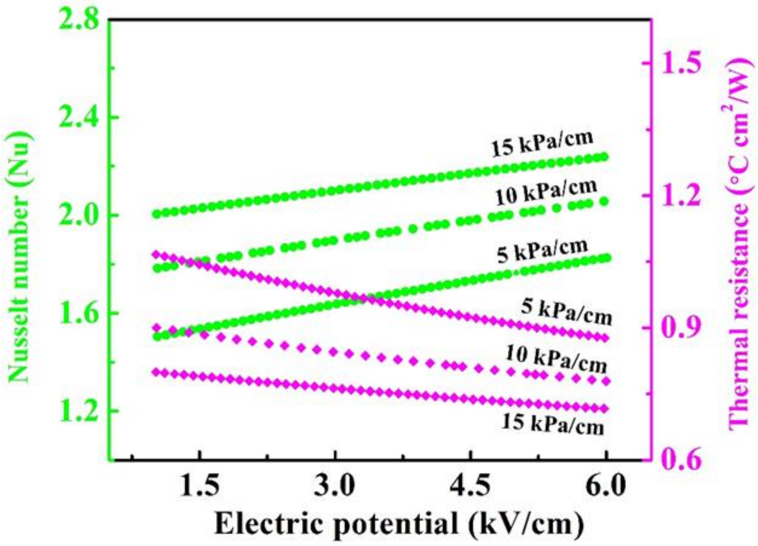
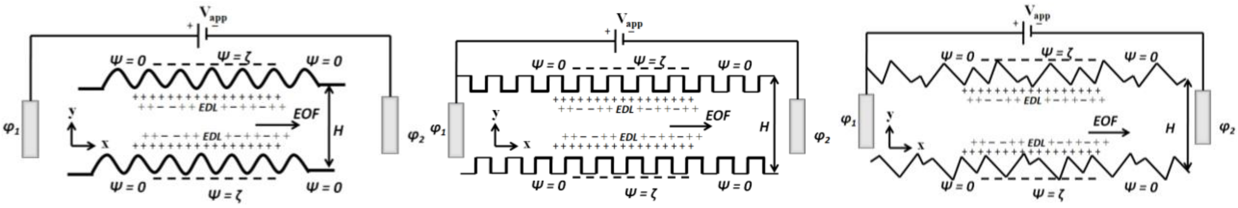


Figure 4. Influence on Nusselt number and thermal resistance due to electric potential for different driving pressure.

Electro-osmotic flow in microchannel having roughened wall surface was also studied quite often. Firstly, the term “surface roughness” can only be used if surface ruggedness is much lesser than channel height. But, in case of microchannel, surface ruggedness is of same order as that of channel, so the term wall ruggedness is better to use. Chen and Cho [18] opted different sinusoidal ruggedness $\left(0.2 \leq \frac{h}{H} \leq 0.85\right)$ in their computational approach. They investigated the species mixing for EOF in smooth and roughened microchannel. It was observed that microchannel having roughened wall has increased mixing efficiency because of larger interfacial contact area. While in smooth microchannel, lower mixing is observed due to low Reynold flow. For sinusoidal ruggedness $\left(0.001 \leq \frac{h}{H} \leq 0.1\right)$ in planar microchannel, yang and liu [19] observes bulk flow velocity and volumetric flow rate decreases rapidly for$0.005 \leq \frac{h}{H} \leq 0.05$ and decreases slowly outside of this range. In another work, they pointed that if edl thickness is about 0.3 times of wall ruggedness height, the flow rate of eof is reduced.

However, for much lesser or larger EDL, the EOF was least affected by the wall ruggedness [20]. Using Nernst–Planck model, Kang and Suh [21] numerically investigate EOF in microchannel having wall ruggedness in form of rectangular elements. It was pointed that EOF depends on shape ruggedness but having distinctive characteristics when EDLs are not overlapped. They also observe circulation zone in EOF for high wall ruggedness geometry similar to pressure driven flow. Yauet al. [22] performs numerical study on microchannel with sinusoidal surface ruggedness $(0.01 \leq \frac{h}{H} \leq 0.25)$ and pointed that electric field and velocity profile modifies along rugged region. Using non-Newtonian fluids in rugged microchannel, Cho et al. [23] examine the electro-osmotic flow and conclude that rectangular element has enhanced flow fixing compared to sinusoidal patterned elements. However, with increase in length and height of rugged region, there is increase in mixing efficiency. Jiang et al. [24] demonstrated the feasibility of EOF for two phase microchannel heat sink. Fakhari and Mirbozorgi [25] uses three different ruggedness profile i.e., sinusoidal, saw teeth and square teeth as depicted in Figure 5. They conclude that wall roughness has significant contribution on laminar electroosmotic flow as surface roughness disrupts the ionic and dynamic flow near to channel wall. They reported that the minor surface roughness of 0.5 µm would results in reduction of 22.3% in mass flow rate relative to smooth microchannel. Sheikhizad and Kalteh [26] have used the Lattice Poisson-Boltzmann method to perform a numerical investigation on a microchannel with an electroosmotic and pressure-driven Newtonian nanofluid flow. They revealed that when the pressure force increases under the action of constant electric field, Nusselt number falls, whereas it increases as the electric field increases for constant pressure force. They concluded that the velocity field quantity and direction are controlled by the heterogeneous surface potential, which drives the vortices toward the channel sides. As shown in Figure 6 (a), Lynn et al. [27] presents a microchannel with primary axial flow that is pressure-driven, as well as secondary flows that are created electro-osmotically by adding electrodes beneath the channel. They have also adjusted the distance between the electrodes to change secondary flow along the channel length.

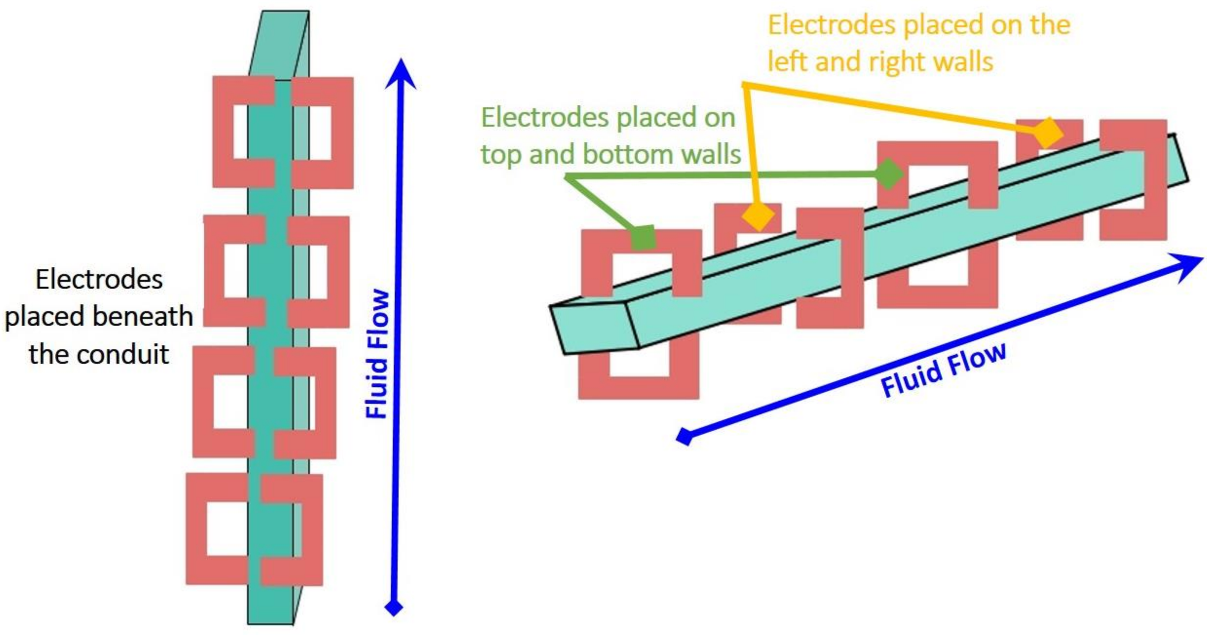
They claimed that efficient mixing can be achieved within 6 mm of the inlet for specific operating conditions and electrode gaps along the microchannel width. Further, Krishnaveni et al. [28] proposes microchannel having electric fields with a periodically alternating direction as shown in Figure 6 (b). The periodic variation of electric field results in crossing of streamlines, which is responsible for chaotic mixing and is qualitatively characterized by obtaining Poincaré maps.



(a) (b) (c)

Figure 5. Ruggedness profile opted in microchannel wall (a) sinusoidal; (b) square teeth; (c) saw teeth.

<u>Pulsating flow.</u>
Usually flow through microchannel is having uniform velocity profile at inlet cross section. After entrance length in microchannel, the flow gets fully developed and Nusselt number does not varies afterwards. Despite uniform velocity profile, researcher also focuses on pulsatile flow in microchannel to enhance the performance.



(a) (b)

Figure 6. Schematic of electro-osmotic flow with pressure driven flow having (a) electrodes beneath the channel. (b) electric fields with a periodically alternating direction

Narrein et al. [29] investigated a helical microchannel heat sink with nanofluids (Al_2O_3/water) numerically. They compare performance for steady and pulsatile flow (Sinusoidal velocity profile). It was observed that pulsatile flow has better heat transfer with marginal reduced pressure drop. They have also determined that for sinusoidal pulsatile flow, Nusselt number rises with increase in amplitude and frequency at lower Reynolds numbers, while at higher Reynolds numbers, the fluctuation is not significant. In another work, they implemented pulsatile flow in helical microchannel heat sink filled with porous medium [29]. Use of porous media with sinusoidal velocity inlet conditions has augmented performance compared to steady flow. Using Navier-Stokes equation, Nandi and Chattopadhyay [30]. implemented pulsatile flow (sinusoidal profile) in a wavy microchannel. They concluded that flow pulsation was able to enhance heat transfer with reduced pressure drop even at low range of Re. In another work [31], they consider Raccoon

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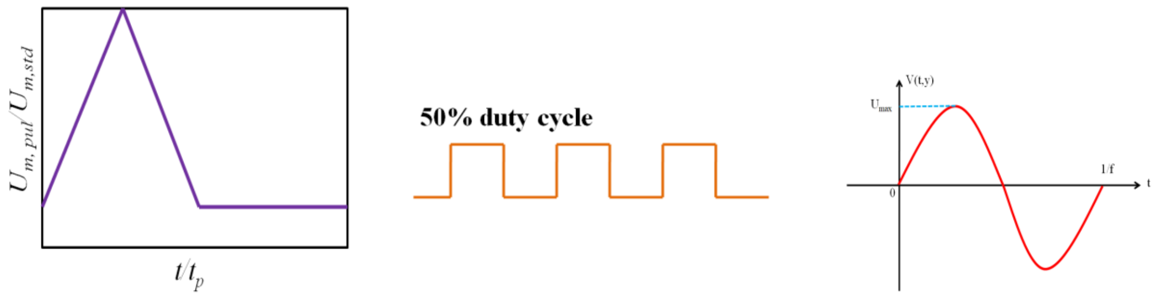
type microchannel (Wavy channel having phase angle of 0° between crest and trough on side walls). They represent different frequency and amplitude of pulsatile fluid flow by Strouhal number (St) and reports maximum thermal enhancement was achieved for St = 5. Recently, Wang et al. [32] implemented triangular waveform at inlet cross section in Louvered microchannel heat sink. In their numerical technique, lattice Boltzmann method was opted for simulation. They conclude that pulsatile flow in a louvred microchannel improves the louver's guiding effect. Furthermore, it offers a combination of contraction and expansion vortex formations, which optimizes fluid flow mixing and heat transfer. Xu et al. [33] in 2021, proposes a novel microchannel heat sink where they implemented pulsatile flow, phase change material (PCM) and nanofluid. The novel microchannel design opted has two layers, where nano fluid (Graphene oxide particles) flowing through upper layer having pyramid pin fins while bottom layer has square pin fins and PCM cavities filled with CNT (carbon nanotube) and paraffin. Their experimental study was conducted with square waveform pulsatile flow. It was observed that pulsatile flow having frequency around 6 Hz has shown maximum performance. They also observe substantial enhancement of 20-50% in Nusselt number with paraffin/CNT composite and pulsating flow compared to grease and steady flow. Different pulsatile waveform used in microchannel heat sink is depicted in Figure 7.



(a) (b) (c)

Figure 7. Different pulsatile waveform used in MCHS in previous literatures.

<u>Magnetohydrodynamics (MHD) flow</u>.

Magnetohydrodynamics (MHD) flow can also be used to improve heat transfer since the magnetic field influences the flow and heat transfer characteristics of the magnetic fluid [34]. Magnetic fluids are those fluids which have magnetic nano particles in them. Many authors have worked on MHD flow, but here only MHD flow in microchannel has been mentioned.

The EOF in a hydrophobic microchannel with an external source magnetic field was theoretically investigated by Ganguly et al. [35] and Shit et al. [36]. Their work shows that the magnetic field can be implemented for alteration in fluid flow velocity. Sheikholeslami and Rokni [37] investigated the nanofluid flow convection under the presence of induced magnetic fields. They conclude that the nanofluid flow decreases with the Hartmann number. Zhao et al. [38] investigated the thermo-hydraulic characteristics of nanofluid in horizontal microchannel under presence of EDL and magnetic field effects. They concluded that both body forces (EDL and magnetic field) can be used to influence heat transfer in microchannels.

Yang et al. [39] apply a lateral electric field along x and z-direction (i.e., E_x and E_z) and a vertical magnetic field (along y-direction, B_y) to a rectangular microchannel with a pressure gradient, as illustrated in Figure 8. They observe below critical Hartmann number (Ha), Nusselt number has downward trend with increase in imposed magnetic field while reverse trend is observed for Ha exceeding critical value.

In addition to magnetic field, pulsatile flow, nanofluids and micro fins tube was studied simultaneously by Naphon and Wiriyasart [40]. The combined heat transfer techniques have shown huge potential in improved thermal performance. They conclude use of pulsatile flow and magnetic field offers Brownian motion of nano particles in the base fluid. In addition to experimental studies, the researchers have simulated the fluid flow in microchannel using various commercial code ANSYS Fluent module, COMSOL, OPENFOAM, and others [17,41]. These multiphysics software not only provide easier way to comprehend the flow dynamics but also helps in optimizing the performance of heat sink.

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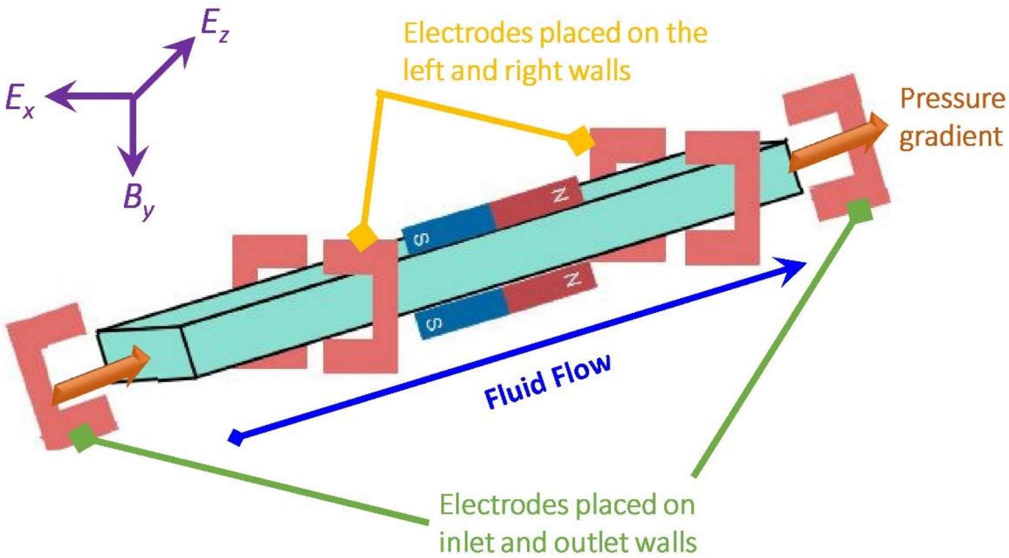

Figure 8. Electromagnetic effect opted in rectangular microchannel.

Vibration

In 2003, Go [[42] demonstrated that thermal performance can also be increased by enhancing the displacement of vibration of the microfin. He determined the influence of flow-induced vibration on the improvement of heat transfer performance. He compared the thermal performance based on thermal resistance encountered in plain-wall and microfin array heat sink. The evaluated heat transfer rate was found to be an increase of 5.5 and 11.5% at air velocities of 4.4 and 5.5 m/s, respectively. The microfin's flow-induced vibration was characterized by microfin flow sensor, which revealed that it vibrates with fundamental natural frequency, irrespective of the velocity of air. And, with the increase of air velocity, vibration displacement of microfin was also found to be amplified. After threshold limit of air velocity, vibration displacement of microfin saturates. He achieved maximum thermal performance (under the structural and geometric constraint) at the junction of restraint of the bending angle and minimum thickness of microfin.

Other active technique

Flow mixing can also be achieved with the help of acoustic effects depending upon the type of fluid used. Another active technique that is not very much common and was very often considered in microchannel heat sink is variable roughness structure technique. The reason for its not using more often is complexity associated with it [43].

Future Scope.

The current study focuses on a variety of active approaches either employed in Microchannel heat sink or has potential in microchannel heat sink. Active approaches either can be used individually or can be used in combination like electrostatic forces, magnetohydrodynamic forces can be used with pulsatile flow for improved performance. Furthermore, instabilities occurred due to two-phase flow boiling in microchannel can also be supressed by active techniques and has not been explored much. The present work has covered only active techniques; however, these techniques can also opt with passive techniques like microchannel design modification, working fluid modification, to further explore the heat transfer enhancement possibility. Furthermore, the local random hotspot generation seriously hampers the service life and performance, so there is a requirement of more efficient method to eliminate it. Most researchers have performed their studies using deionized water as a coolant. However, there is a potential risk of short circuit, so dielectric coolant like HFE 7000 can be developed.

Impact

One of the biggest worries for environmental sustainability is waste generation due to an upsurge in electronic component failure. The major reason for failure of such components is improper thermal management. Also, the performance of electronic products like smart phones, laptop, and PCs depends on the number of CPU present. Moreover, with increase in number of CPU, the heat generation is enhanced. So, there is a requirement of innovative cooling techniques. Among various techniques, Microchannel heat sinks have demonstrated its utility in the proper thermal control of high heat flux dissipation devices, ensuring their commercial application. Apart from electronic cooling, microchannel heat sink has wide applications in numerous technologies like in battery thermal management system of hybrid electric vehicle, cooling of solar photovoltaic module, and others. The space and material cost pertaining to manufacturing and assembling of microchannel heat sink is relatively lesser than other techniques. Furthermore, Inventory of coolant required is also less, which is important from economic and security point of view. With time, the evolution of micro fabrication techniques like laser cutting, wire-cut electric discharge machining, micro milling, embossing, laser beam machining, chemical etching has helped the researchers to explore new possibilities in this domain. The quicker response time due to very less thickness of microchannel walls is also one of the reasons for widespread of microchannel heat sink. The main objective of Manufacturers is not only to augments the heat transfer rate of microchannel heat sink by active and passive approaches but also to reduce the cost of chip making so that large scale production can be ensured.

Conclusion

As electronic industry has been flourishing, the components and devices are facing problem of thermal management. The improper management not only lowers the efficiency but also causes permanent damage. To solve the issue, numerous techniques have been explored. Heat transfer intensification in microchannel heat sinks has been accomplished via active techniques, which uses an external power supply. Flow pulsation, electro-osmotic flow, magneto-hydrodynamics flow are active techniques that has shown significant enhancement. However other innovative techniques are also in developing phase. These techniques can be integrated with passive techniques for additional augmentation, and they have a great potentiality in terms of thermal enhancement in microchannel heat sinks.

Conflict of interest

The author declares that there is no conflict of interest.

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