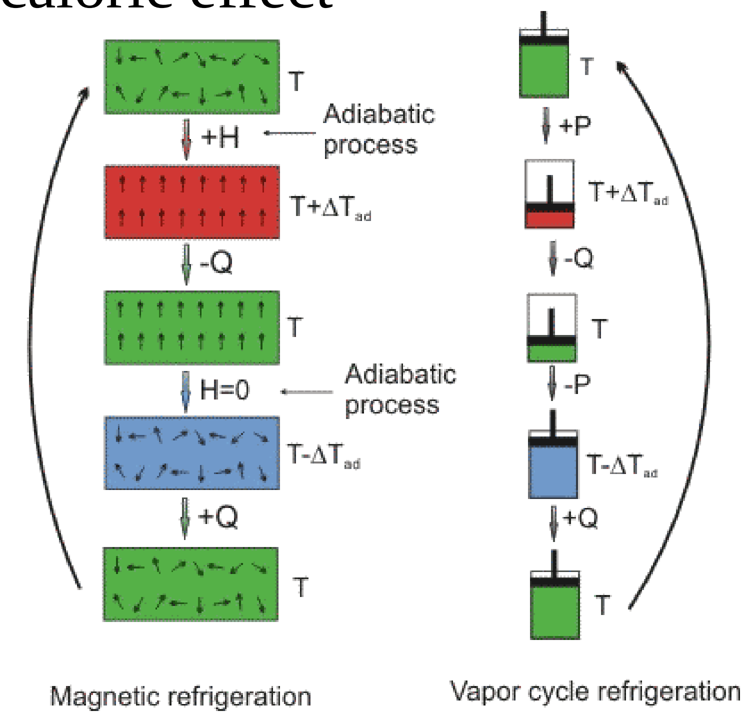
MAGNETO CALORIC EFFECT

Principle: Magneto caloric effect



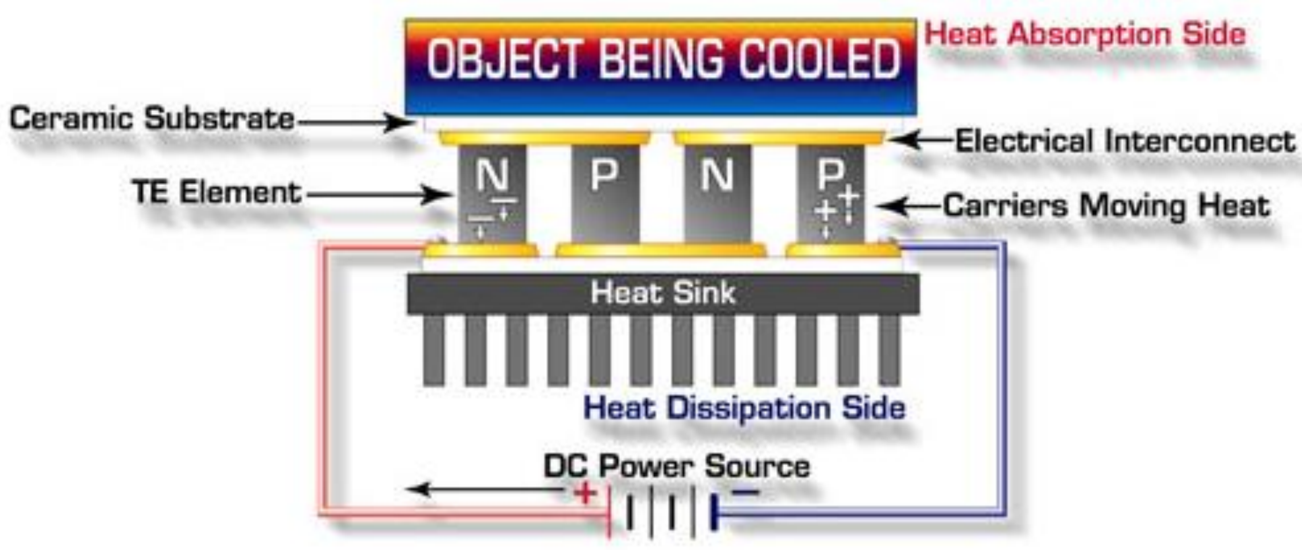
Application of magnetic field to a MCE material causes the material to heat up that is removed by suitable coolant. The temperature of material decreases by removing magnetic filed after which heat from cooling target is added to the material

Fig 1: Comparison of magnetic and conventional refrigeration

Source: Google images

THERMOELECTRIC COOLING

Principle: Peltier effect

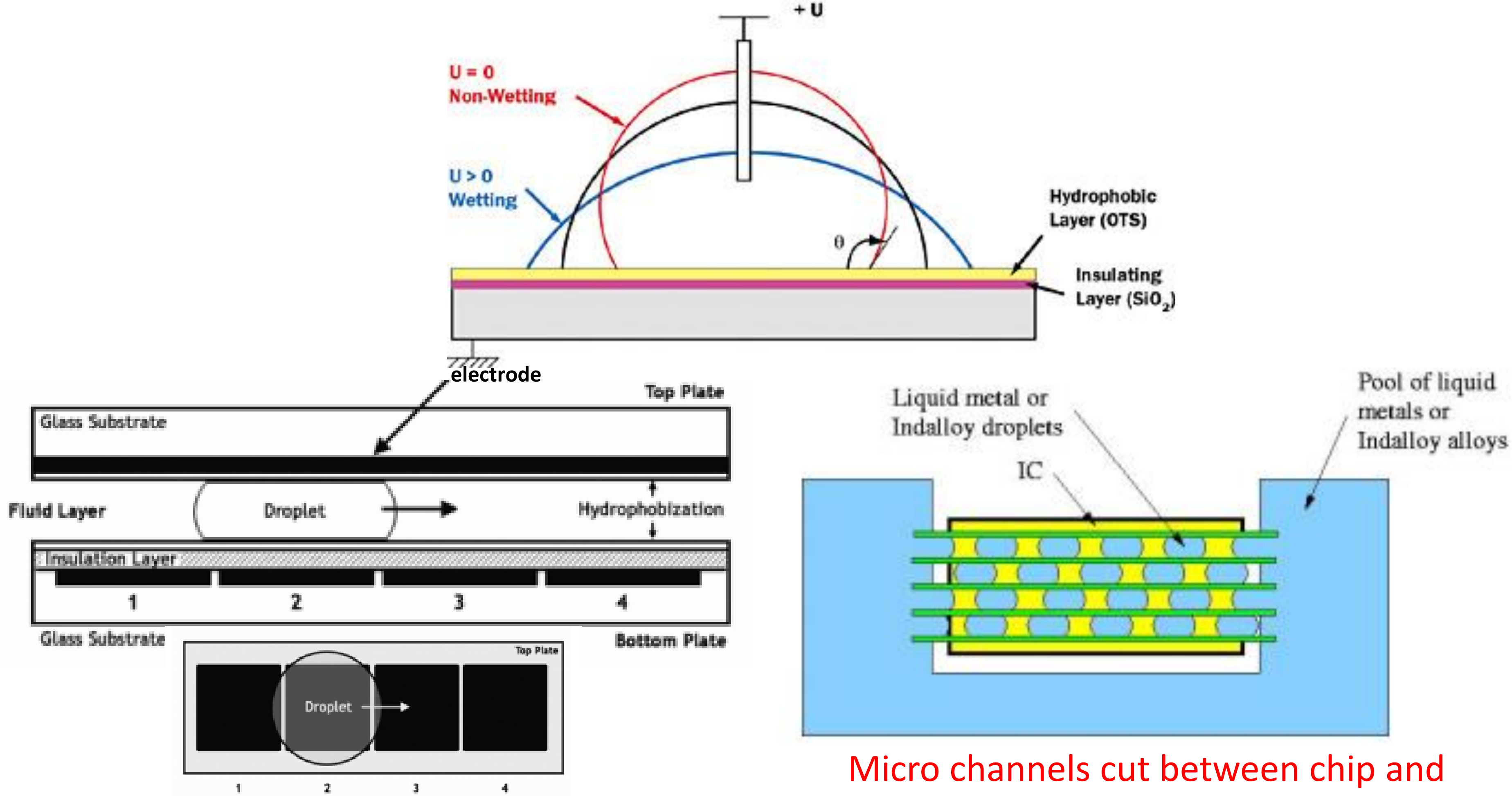


Application of voltage to thermocouple causes one end to heat up and other end to cool where the target body is located

Fig 2: Thermoelectric cooling

Source: Google images

ELECTRO WETTING



Sequential application of voltage to electrodes causes the water drop to move

Micro channels cut between chip and electrode to allow movement of water droplets in the micro channel

Fig 3a: Principle of electro wetting and cooling for electronics by electro wetting

Source: An Electrowetting-Based Technique for Hot-Spot Cooling of Integrated Circuits: by S. Alavi,et al (2012)

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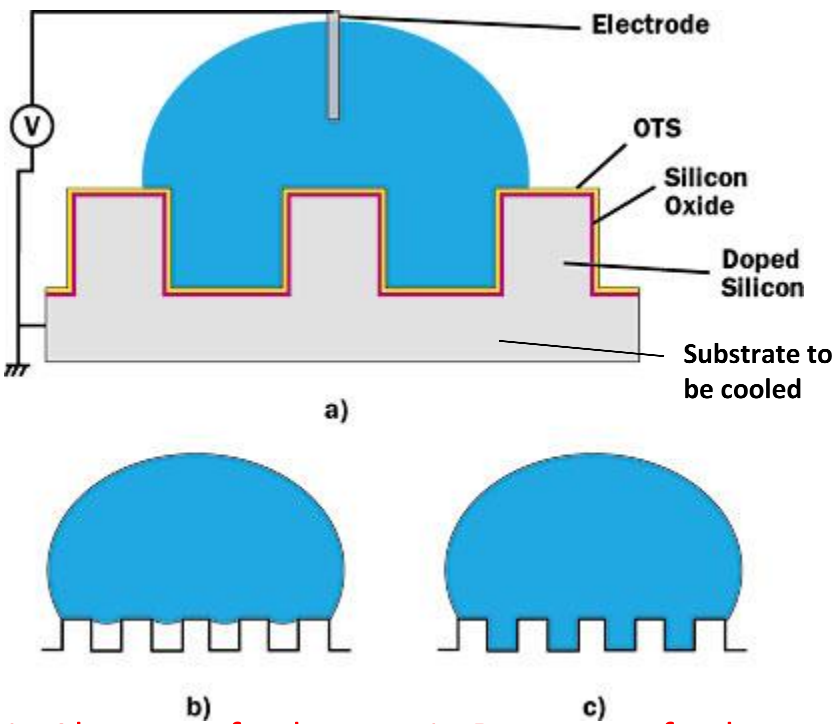
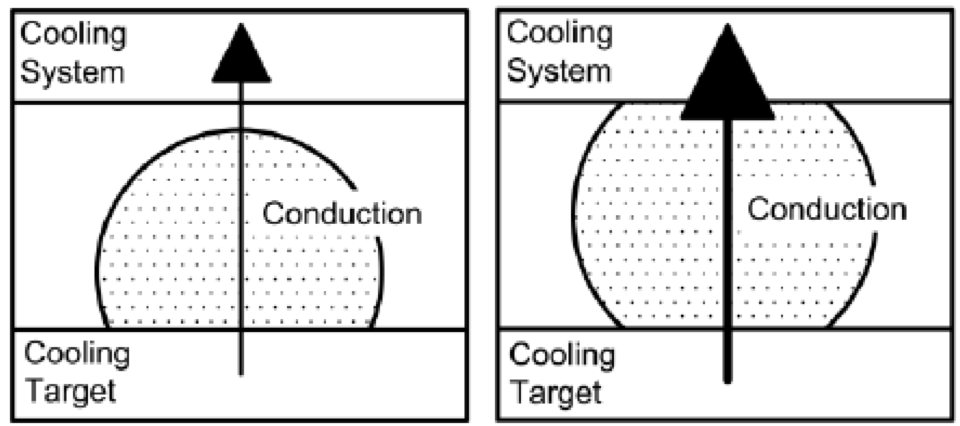


In Absence of voltage Resistance is offered by air gap and water

In Presence of voltage resistance is offered by water only



Heat transfer mechanisms during

Absence of voltage Presence of voltage

Fig 3b:Cooling for electronics by electro wetting by using thermal switch

Source: An Electrowetting-Based Technique for Hot-Spot Cooling of Integrated Circuits: by S. Alavi,et al (2012)

Inference from literature review

Thermoelectric cooling:

- The efficiency of TEC :- 5 to 15 % compared to 40-50% of conventional refrigeration.
- Lower figure of merit for thermoelectric materials with highest being 2.5 till date.

$$(\mathbf{COP}) = \frac{\mathbf{T_C}}{\mathbf{T_h} - \mathbf{T_C}} \frac{\sqrt{\mathbf{1} + \mathbf{ZT_m}} - \frac{\mathbf{T_h}}{\mathbf{T_c}}}{\sqrt{\mathbf{1} + \mathbf{ZT_m}} + \mathbf{1}}$$

Source:A review of thermoelectric cooling: materials, modelling and applications by Rupert Gouws , et al (2014)

Magnetic caloric effect:

- Gd based materials exhibit giant MCE but are costly.

- No MCE materials discovered are able to obtain higher temperature difference with higher cooling load.

Demonstrator	Max. cooling power	Mass of material	Max. temperature span
Max. cooling power			
Okamura et al.(2007)	**540W**	4000g	8K
Engelbrecht et al.(2012)	**1010W**	2800g	19K
Jacobs et al.(2013)	**3042W**	1520g	20K
Max. temperature span			
Arnold et al.(2011)	31W	136g	**30K**
Arnold et al.(2013)	96W	650g	**33K**
Arnold et al.(2011)	42W	170g	**42K**

Source: Magneto caloric Cooling Near Room Temperature by Robin Langebach ,et al (2014)

Electro wetting:

- The challenges in electro wetting include

I. Exploring alternative liquids to achieve even higher thermal conductivities.

II. Implementing alternative dielectric materials to insulate the electrodes from the droplet in order to achieve even faster droplet transport speeds.

III. Electro wetting using AC for different rms and frequencies.

RESULTS OF LITERATURE SURVEY

COMPARISON OF COOLING TECHNOLOGIES

Parameter	Thermoelectric cooling	Magnetic refrigeration	Electro wetting Cooling
Entropy density	Low	High	Low
COP/Efficiency	Higher COP with low ΔT.	Higher COP.	Highly efficient.
Economic aspect (In comparison to conventional refrigeration)	High capital cost.	Low cost .	Low cost.
Cooling capacity/Max Heat flux/ΔT	200W for ΔT= 0 for bismuth telluride based thermoelectric materials (single).	3.7 K.	Up to 60W/cm^2 for d_l=1mm,d_w=1.5mm, water with oil as filler fluid.

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Parameter	Thermoelectric cooling	Magnetic refrigeration	Electro wetting cooling
Power consumption	Linear function of ΔT.	Less by 30-40% as compared to conventional refrigeration.	Micro watts.
Barriers/ challenges	There are no materials with higher ZT values.	Cost of GMCE materials and strength of magnetic field that can be produced by magnets.	Alternate liquids and dielectric materials to enable faster transport of fluid and size scalability of esystem.

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Parameter		Thermoelectric cooling	Magnetic refrigeration	Electro wetting cooling
Temperature range applicability	**Low temp region (<15K):-**	Inapplicable.	Technically mature.	Not applicable.
	Med temp region (15-77K):-	Difficult to apply.	Small applicable scope.	Not applicable.
	High temp region (>77K):-	Good applicability.	Applicable, Technically immature.	Applicable.

***Analysis results could not be shared due to confidentiality**