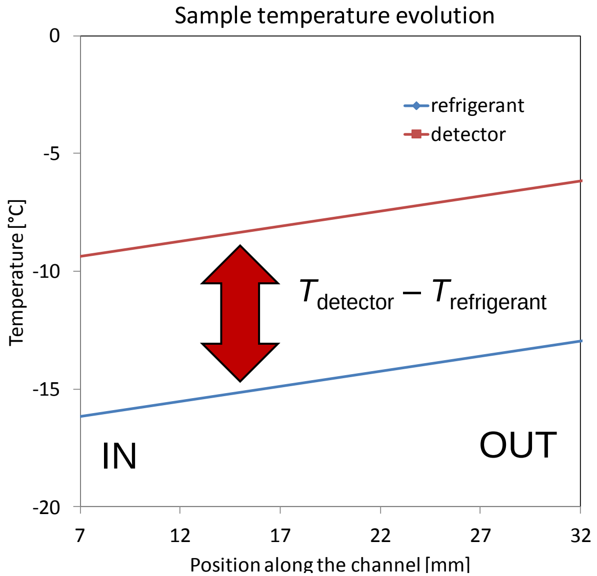
Minichannels for single-phase cooling

- General considerations on pressure drop and material budget -

Mass Flow Rate (single-phase)



❑ The LOCAL temperature difference between detector and refrigerant depends on the LOCAL heat flux, refrigerant heat transfer coefficient and thermal resistance (glue, etc…).

❑ If heat flux, gluing and geometry are uniform, ($T_{detector}$ – $T_{refrigerant}$) is uniform all along the stave.

❑ To a first approximation, the temperature variation is the same for the detector and the refrigerant.

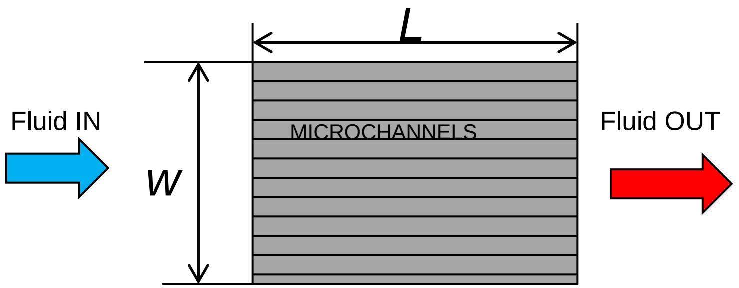
❑ In order to achieve 5 K temperature uniformity on the detector, the refrigerant mass flow rate must be high enough to keep the refrigerant temperature rise $T_{out} - T_{in} < 5$ K

$$Q = mc_p(T_{out} - T_{in})$$

❑ The minimum required mass flow rate depends on the specific heat c_P of the refrigerant.

Low mass flow rate → **Small channels** → **Low x/x_0**

Mass flow rate for ITS Upgrade



w = 15 mm, L = 210 – 370 mm
C_6F_{14}: c_p@15°C = 1037 J kg^{-1} K-^{1}
water: c_p@15°C= 4188 J kg^{-1} K-^{1}

Refrigerant	q [W cm^{-2}]	L [mm]	Q (per stave) [W]	m (per stave) [g/s]
C_6F_{14}	0.5	370	28	5.4
Water				1.3
C_4F_{10}* (2 bar)				0.6
CO_2* (51 bar)				0.3
R717*(7 bar)				0.05

* *Evaporative cooling examples, saturation temperature 15 °C, vapor quality in/out 0.2/0.7*

- ❑ C_6F_{14} is a dielectric refrigerant.
- ❑ Water allows to decrease the mass flow rate by around 4 times as compared to C_6F_{14}.
- ❑ The mass flow rate with water is only double the mass flow rate required by evaporative cooling with C_4F_{10}.

PRESSURE DROP CONSTRAINT

Refrigerant Pressure Drop Constraint

- Water: < 0.5 bar in order to keep the pressure < 1 bar and avoid leakages
- C_6F_{14}: no constraints (dielectric fluid)

Material Pressure Constraint

- Silicon: 10 bar (pressure constraint for GTK/NA62 silicon microchannel cooling system)*
- Polyimide: ?
- The pressure constraint (and x/x_0) strongly depends on the thickness of the walls

x/x_0 due to Refrigerant Only

Single Channel a X b

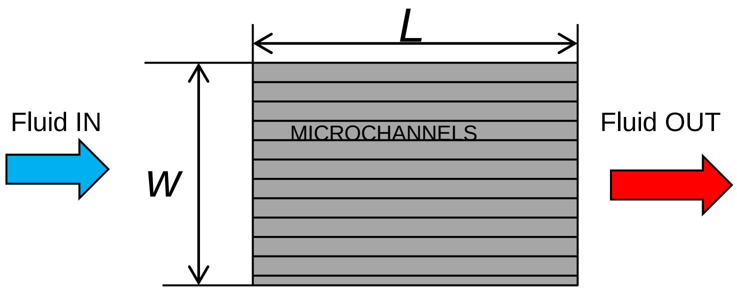
	a [μm]	*b* [μm]	channels	x/x_0 [%]	Pressure Drop [bar]
C_6F_{14}	60	15000	1	0.03	9.5
C_6F_{14}	160	15000	1	0.08	0.5
Water	53	15000	1	0.01	9.5
Water	140	15000	1	0.04	0.5

x_0 C_6F_{14} = 0.19 m, x_0 water = 0.36 m
x_0 silicon = 0.09 m, x_0 polyimide = 0.29 m

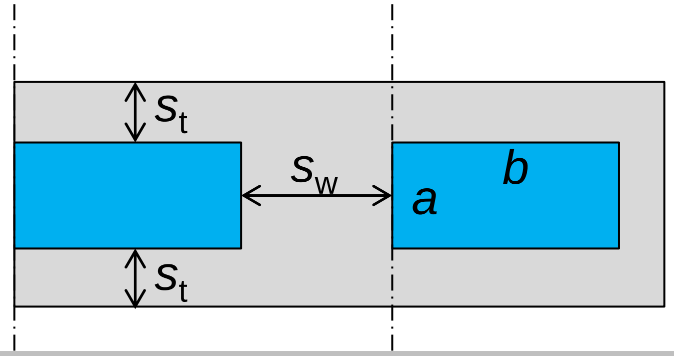
** EDMS1157976 v.2*

C_6F_{14} - SILICON

Constraints: refrigerant ΔT = 5K, pressure drop < 10 bar



w = 15 mm, *L* = 210 mm, *q* = 0.5 W cm^{-2}



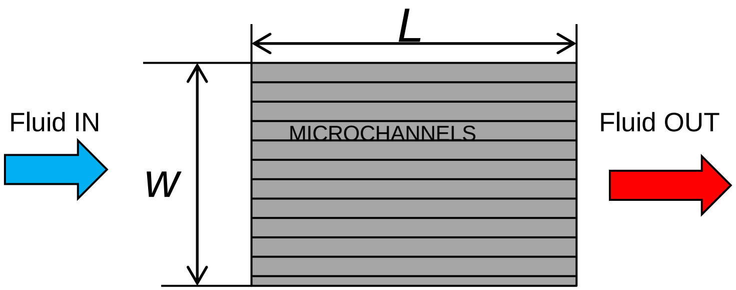
x_0 silicon = 0.094 m, x_0 C_6F_{14} = 0.190 m

a [μm]	*b* [μm]	s_t [μm]	s_w [μm]	channels	x/x_0 [%]	Pressure Drop [bar]
100	100	25	100	75	0.13	9.7
100	300	25	100	38	0.12	3.4
70	280	25	100	39	0.10	9.6

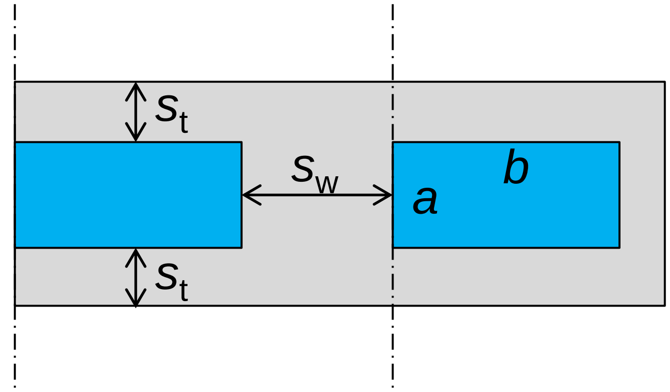
- ❑ 70~80% of the global x/x_0 is due to silicon.
- ❑ Some improvement can be obtained with high aspect ratio channels.

WATER - SILICON

Constraints: refrigerant ΔT = 5K, pressure drop < 0.5 bar



w = 15 mm, L = 210 mm, q = 0.5 W cm^{-2}



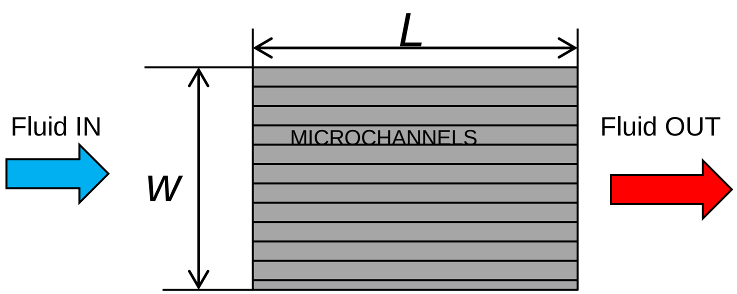
x_0 silicon = 0.094 m, x_0 water = 0.360 m

a [μm]	b [μm]	s_t [μm]	s_w [μm]	channels	x/x_0 [%]	Pressure Drop [bar]
210	210	25	100	48	0.17	0.5
210	630	25	100	21	0.13	0.2
160	480	25	100	26	0.12	0.5

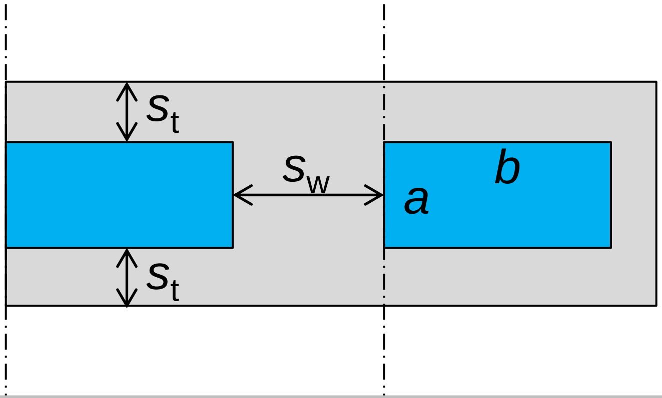
- ~70% of the global x/x_0 is due to silicon.

WATER - POLYIMIDE

Constraints: refrigerant ΔT = 5K, pressure drop < 0.5 bar



w = 15 mm, L = 210 mm, q = 0.5 W cm^{-2}



x_0 polyimide = 0.29 m, x_0 water = 0.36 m

a [µm]	b [µm]	s_t [µm]	s_w [µm]	channels	x/x_0 [%]	Pressure Drop [bar]
210	210	25	100	48	0.08	0.5
200	800	25	100	17	0.07	0.24
200	800	50	200	15	0.09	0.27

- 30~50% of the global x/x_0 is due to polyimide.

Conclusions

- Water/C_6F_{14} and silicon/polyimide have been considered.
- The maximum pressure drop and manufacturing constraints have a strong influence on the achievable x/x_0.
- Water: low flow rate and high x_0 but pressure drop must be < 0.5 bar.
- C_6F_{14}: higher flow rate and lower x_0, but higher pressure drop.
- Silicon: allows higher pressure but displays low x_0.
- Polyimide: lower pressure allowed, but displays high x_0.
- In order to reduce the x/x_0, polyimide may be a better option for water and silicon may be a better option for C_6F_{14}.
- High aspect ratio channels allow to improve both pressure drop and x/x_0.
- **x/x_0 reasonable target for silicon/C_6F_{14} or polyimide/water: ~ 0.10%**