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Detector cooling R&D with multi-micro-channels: lessons learned & open issues

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Due to their superior thermal performance, multi-micro channel cooling devices in different layouts and geometries are being proposed for the thermal management of particularly demanding sectors of silicon trackers in HEP experiments. Especially for boiling flows, the design of those devices must anticipate known issues such as oscillating flows and flow maldistributions from a common manifold into the individual micro-channels, which otherwise can cause local hot spots and severe pressure fluctuations. The introduction of restrictions/capillaries at the channel inlet is a well-established method to apprehend such flow instability phenomena. The hydraulic backward-facing step created by such restrictions at the inlet of the main micro-channels serves additionally as a trigger for boiling onset, due to the drop in the static pressure in the near-wall region, and thus enhances the efficiency of the cooling device. However, if the channel design and the target flow parameters are not chosen carefully in tandem, the above mentioned general micro-channel layout (i.e. a succession of manifold, inlet restriction and main micro-channel) may induce cavitation and other surface damaging phenomena.
The proposed presentation will introduce this issue, starting from examples of high-speed camera flow visualisations and "post-mortem" analyses of silicon-glass multi-micro-channels from the first generation of R&D prototype devices used with boiling flows of carbon dioxide. A short literature review on the issue of cavitation and its related damage at the micro-scale will be presented, some damaged micro-channels at hand will be shown and discussed and an analytical procedure resulting in a "parametrical map" to eliminate the critical working conditions will be proposed. This allows for the prevention of damaging flow regimes within existing device layouts, and provides guidelines that can then be applied to the design of any micro-channel cooling layout conceived in the future.
Whilst far from being fully resolved, the issue deserves much more attention and a plan of action for the future will be proposed, also in view of the new era of micro-channel detector cooling, which is aimed away from costly Silicon devices and towards 3D-printed light-weight realisations in metals or ceramics. In particular, any potential pitting damage may prove much more disastrous for 3D-printed structures, compared to those produced by MEMS techniques in monocrystalline silicon or glass. This in conclusion underlines the necessity of a better understanding regarding the damaging potential of the flow/structure interactions, in order to safely design and operate future on-detector cooling devices.

Authors: HELLENSCHMIDT, Desiree (CERN); PETAGNA, Paolo (CERN)

Presenter: HELLENSCHMIDT, Desiree (CERN)