Cooling system study for the 4M Pixel AGIPD

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Abstract

The Adaptive Gain Integrating Pixel Detector(AGIPD) is a hybrid pixel detector which is targeted for use at European XFEL. For a more precise digitization, it's decided to redesign the electronics for 4M AGIPD and place all the digitization in vacuum. Therefore special cooling system must be developed for PCB cooling. This report shows the experiment and simulation for testing the cooling concept which is under study. The experiment is performed to measure the absolute thermal resistance of the testing system. Meanwhile, simulation work is undertaken in ANSYS Fluent to simulate the heat transfer and give some suggestion for further research.

Contents

1 Introduction

1.1 AGIPD

The Adaptive Gain Integrating Pixel Detector(AGIPD) is a hybrid pixel detector developed by DESY, PSI and the University of Bonn and Hamburg. It is targeted for use at European XFEL, a source with unique properties as Figure 1 shows: a train of up to 2700 pulses is repeated at 10 Hz rate. The pulses inside a train are $\leq$ 100 fs long and separated by 220 ns, containing up to 10^{22} photons of 12.4 keV each.
To meet the requirement of XFEL, AGIPD consists of 500 μm thick sensors to provide a high efficiency to detect photons of 12.4 keV energy. Each sensor features 512$\times$128 pixels, which are 200 μm$\times$200 μm in size. 2$\times$8 AGIPD ASICs are bump-bonded to each sensor for the readout, which will help to achieve freely switching from different amplitude gain factors. The detector system will be operated in vacuum to prevent the intense beam from interacting with ambient air or exit windows, which would lead to huge background.

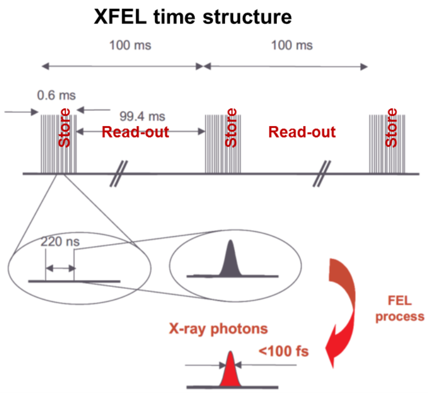

Figure 1: XFEL Bunch Pattern

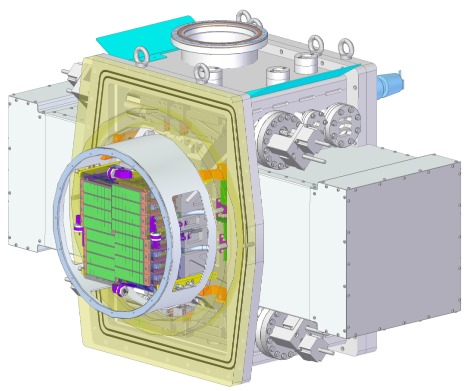

Figure 2: 1M Pixel AGIPD

1.2 Cooling system design

In the 1M AGIPD system, digitization electronics are placed in an external housing, therefore convection in air will dissipate heat from the system. But it is decided to redesign the read out electronics of the 4M AGIPD and perform the digitization on the vacuum boards, where there is no media for heat transfer. Therefore special cooling system has to be developed to prevent the electronics from overheating.
This cooling concept is based on "bathtub" principle: copper container is soldered to PCB and the encapsulated volume is filled with silicon oil. Natural convection in the cavity transfers heat from electronic components to container, and than to the water cooled copper plate.

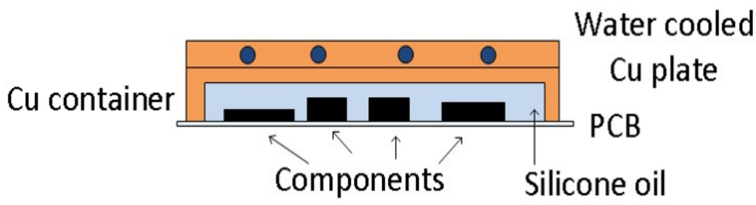

Figure 3: Cooling system for 1M AGIPD

1.3 ANSYS Fluent

ANSYS Fluent is one of the most-powerful computational fluid dynamics (CFD) software tools available. It contains the broad physical modeling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applicationsranging from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from clean room design to wastewater treatment plants. Fluent covers a broad reach, including special models with capabilities to model in-cylinder combustion, aero-acoustics, turbomachinery and multiphase systems.

2 Heat Transfer Theory

2.1 Natural convection

Natural convection is a mechanism of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device) but only by density differences in the fluid occurring due to temperature gradients. The liquid around heat source becomes less dense after heating and flows away from source area under gravity or other force field. Heat will be taken away from the system by this way. In general, convective heat transfer is much greater than conducting, and therefore is usually used in cooling system design. The basic relation for convection is:

$$W = h * S * \Delta T$$

W is the power dissipated by convection, S the exposed area and ΔT the temperature difference between heat surface and fluid. h is the convection coefficient, which is dependent on the property of surface and liquid, and the physical situation.

2.2 Absolute heat resistance

The absolute thermal resistance is a heat property by which an object or material resists a heat flow. It is defined as the temperature difference across a structure when a unit of heat energy flows through it in unit time, so the SI unit is K/W. According to its definition, the absolute thermal resistance of the system could be given as :

$$R_\theta = \frac{T_s - T_c}{q}$$

T_s is the temperature of thermal source, T_c the temperature of cool surface and q the heat flux.

3 Experiment and simulation

3.1 Experiment

To figure out whether the cooling concept will work, a system for testing in air is prepared: the copper container is soldered to PCB, which is equipped with 4 resistors as thermal sources. Meanwhile, a temperature sensor is mounted on each resistor and another one is soldered in the middle of PCB to measure the temperature of the silicon oil.
Absolute thermal resistance is chosen as characteristic of the system. Therefore experiment is performed to measure the temperature of resistors and container surface. Figure 4 and Figure 5 show the measurement with and without silicon oil, powering two neighbouring resistors. An Al heat sink and fan help to increase heat dissipation so that resistors can work at high power without overheating. The calculated R_θ is shown in table. As is seen, the thermal resistance of silicon oil is not constant like solid material because temperature has profound effect on the convection heat transfer in liquid.

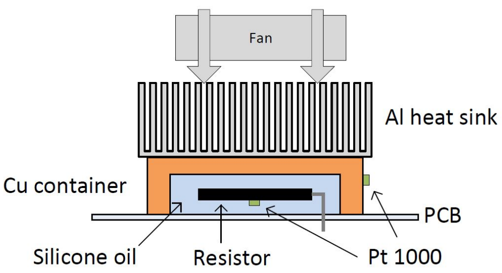

Figure 4: Experiment with silicon oil

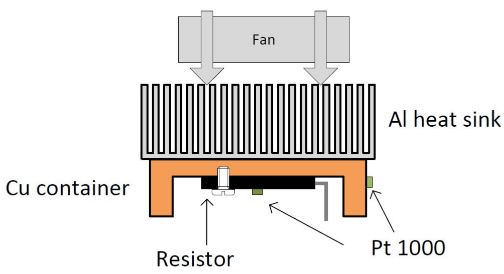

Figure 5: Experiment without silicon oil

power	$4W * 2$	$8W * 2$	$16W * 2$
$R_\theta - copper[K/W]$	0.2	0.2	0.2
$R_\theta - oil[K/W]$	4.8	2.9	1.7

It turns out to be quite complicated because convection in the container is affected by many factors, such as temperature, thermal source distribution and the inside structure of the container. Further research on the thermal resistance is needed. Therefore CFD simulations in ANSYS Fluent were performed.

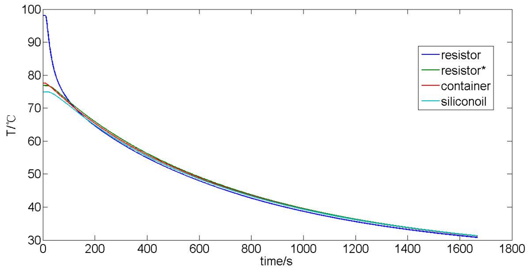

Figure 6: Cooling process in air

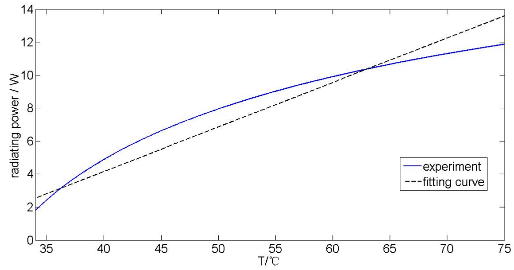

Figure 7: Radiating power-T curve

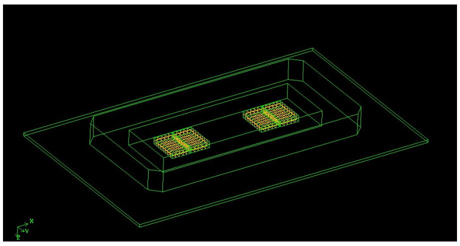

Figure 8: Model for simulation

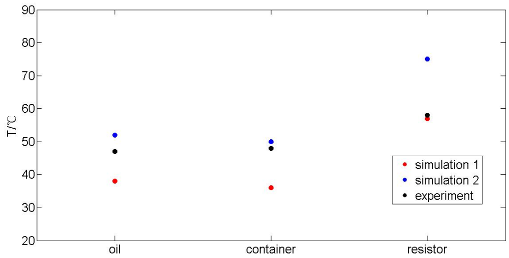

Figure 9: Temperature at $4 * 1$ W

3.2 Simulation

3.2.1 Convection coefficient

The simulation work is undertaken in ANSYS Fluent, a powerful software for flow simulation. At first a simplified model is prepared as Figure 8 because a simple model will effectively shorten the time needed for calculation. In the geometry, the Al heat sink and fan are removed. The container surface is exposed to air directly and heat is dissipated by convection from the system to surrounding air. For a better simulation, the convection coefficient is determined by the experiment shown in Figure 6, which is the measurement of the cooling process in air. The total energy of this system could be estimated according to the following formula:

$$E = C_p * T + C$$

C_p is the thermal capacity of this system, calculated to be 227 J/K. T is the temperature and C a random constant. What really matters is the derivative with respect to time, which means the radiating power of this system. The final result is shown in Figure 7. It's the relation between temperature and radiating power. A linear fit of data gives an average value of h, that is $14.7W/m^2/K$.

3.2.2 Result

The simulation results are shown in Figure 9 to Figure 11. Simulation 1 is done with model A (heat sources have direct contact with the PCB), simulation 2 with model B

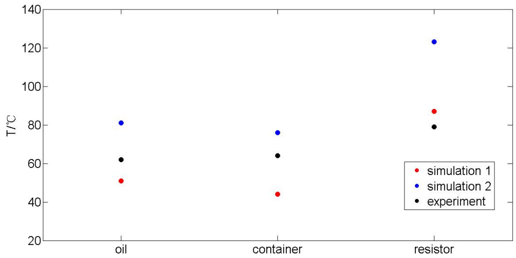

Figure 10: Temperature at $4 * 2$ W

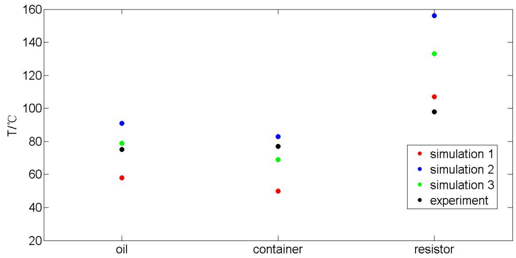

Figure 11: Temperature at $3 * 3$ W

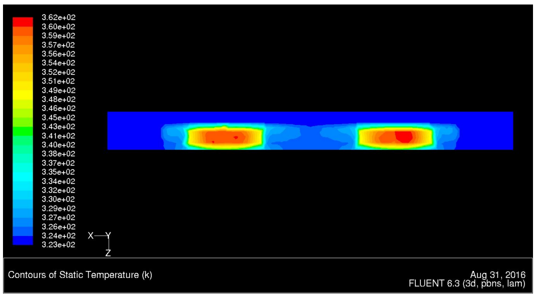

Figure 12: Sectional view at 4*1W

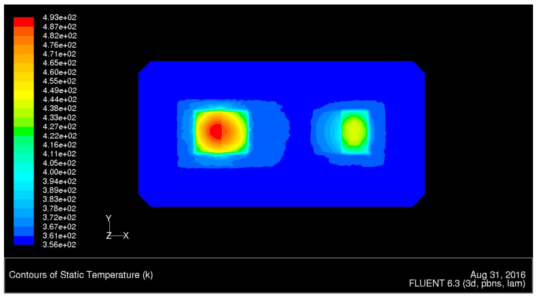

Figure 13: Sectional view at $3 * 3$ W

(heat sources are 2 mm away from the PCB) and simulation 3 is with model B but has a convection coefficient of $20W/m^2/K$. Meanwhile, experiment with the same condition is performed to figure out whether the simulation is reasonable.
As is seen, the temperature of simulation 1 is lower than the one of the experiment, that is because the thermal source has direct contact with the PCB in model A so that the heat flux through PCB increases. The temperature of simulation 2 is always higher. The problem is that convection coefficient is constant in simulation but actually it must be temperature dependent. Figure 11 shows the result of the simulation with a convection coefficient of $20W/m^2/K$. Temperature drops down for about 15 °C comparing with simulation 2, which indicates a more accurate setting for convection coefficient is necessary.
Additionally, temperature distribution varies when changing the thermal source distribution. As shown in Figure 13, the temperature on the left is much higher, especially on the narrow region between two resistors. It indicates that some point could be overheating, which was proved by experiment.
Based on the discussion above, the simulation in ANSYS Fluent could be thought reasonable, but improvement is needed to make it more accurate. There are two points which should be taken into consideration: set the convection coefficient as a temperature-dependent and position-dependent one and give a more precise setting for resistor material. The density, thermal conductivity and thermal capacity is unknown, so that the temperature of resistor in simulation is not reliable.

4 Outlook

To conclude, the cooling concept is effective, but more simulation and experiment are needed to research the temperature distribution and thermal resistance of this system. There are some points for further investigation and optimisation:

- Different thermal source distribution
- Different distance between thermal source and PCB
- Different inner size and structure of the container
- Different no electric conducting liquids

5 Acknowledge

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