

My Summer with PSEC

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1 Overview

1.1 LAPPD

Large-Area Picosecond Photo-Detectors (LAPPDs) are fast-timing photodetectors that cover a large planar area of 400 square cm. As illustrated in Fig 1, they are tiles that consist of several layers: a window with a thin photocathode coating, two Microchannel Plates (MCPs), and transmission line anode strips at the tile base. Each layer is separated by resistive spacers.

LAPPDs enable time resolution of 10 picoseconds and spatial resolution of 700 microns. Many experiments require and would benefit from such high time and spatial resolution. Possible applications include the use of LAPPDs in water Cherenkov neutrino detectors or in collider detectors to reduce the amount of pileup, among others [1].

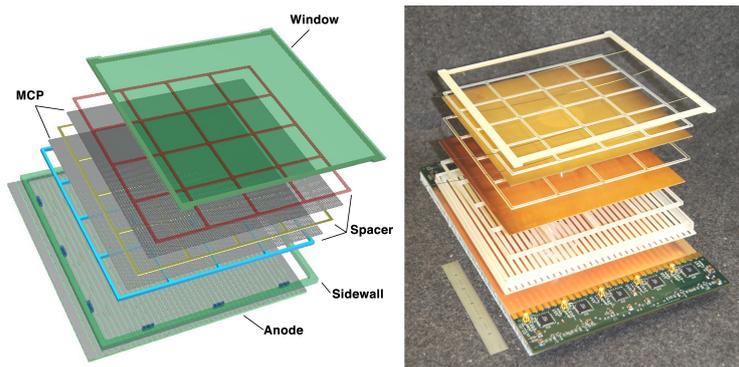


Figure 1: The layers of a LAPPD, image from PSEC Photo Library

1.2 In-Situ Style Fabrication

The PSEC group at UChicago is attempting to improve upon LAPPD technology so that the detectors can be commercially produced at high volume and low cost. The goal of the group is to assemble LAPPDs using an in-situ approach, which would avoid vacuum transfer of the LAPPD tiles by creating the photo-cathode layer after the top seal is already in place [2].

The group is using a two-pump configuration. During the seal and bake-out steps, the contents of the tile are pumped along with the area outside the tile. Then, for the photo-cathode synthesis, the outside vacuum is set to atmosphere and the top of the vessel can be removed leaving the window of the tile accessible (see Fig 2).

1.3 My Involvement

I joined the PSEC group on 5/19/2016, and worked with the group for 12 weeks. When I joined, the group had assembled and sealed an LAPPD tile inside the vessel. The tile consisted of two MCP's and an Indium-Bismuth top seal. Over the course of the 12 weeks we finished constructing the rest of the vacuum manifold, configured a heating system to keep the manifold at a steady temperature, deposited a Cesium photo-cathode layer on the top window, and began preliminary tests of the properties and quality of the photo-cathode.

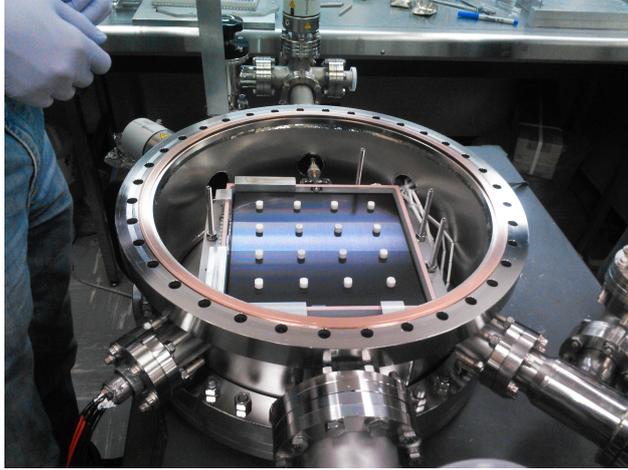


Figure 2: An LAPPD tile being assembled inside the large vacuum vessel

2 Construction of Manifold

Our vacuum manifold has several key components (see Fig 3). The inside of the tile is connected to the rest of the manifold via a glass tube and a Swagelok connection. The manifold connected to the inside of the tile consists of a residual gas analyzer, the "Inside-pump," a pressure gauge, and two Cesium ports. There is also a large vessel which holds the LAPPD tile. Connected to this vessel is the "Outside-pump" and a pressure gauge, as well as paths for temperature & electronics read-out and high voltage.

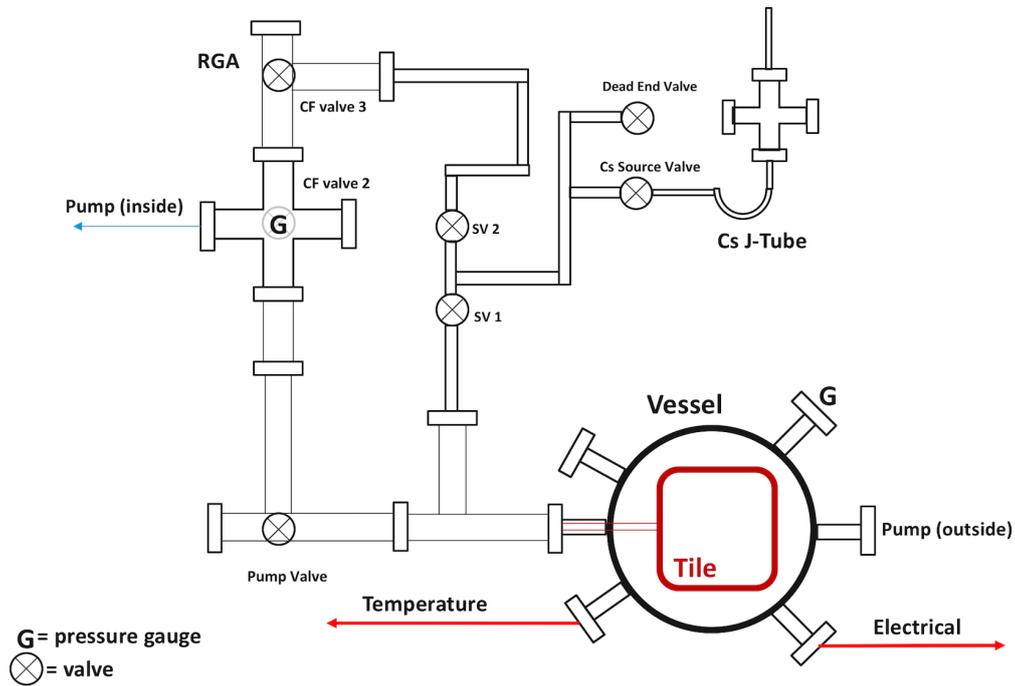


Figure 3: Schematic diagram of the vacuum manifold. Several valves and pipes of varying diameters allow control of conductance.

2.1 J-Tube Design for Cs Source

While most of the manifold design occurred before I joined the PSEC team, I was around for the design of the Cs source J-tube. The Cs break-seal ampoule is placed in aluminum tubing and then welded to a 2 3/4" CF cross. The horizontal faces of the cross have glass viewports, which were intended to visually confirm when we had successfully broken the Cs ampoule, but ended up being vestigial (see Fig 5). We were able to

crimp the aluminum tubing to break the Cs ampoule.

Underneath the ampoule is stainless steel mesh to catch glass fragments. The cesium, which is heated to a gaseous state, flows into a stainless steel J-Tube underneath the cross. The curved part of the tube is kept at a cooler temperature to catch and hold the cesium in its liquid state. By controlling the temperature of the rest of the manifold, we could then direct the cesium towards the tile. The J-Tube connects to a valve, so that the entire segment can be closed off before being removed.

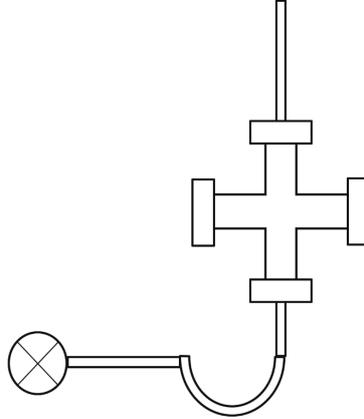


Figure 4: Schematic diagram of the J-Tube



Figure 5: A close up sideview of the cross, featuring the viewports. Cesium not yet mounted

3 Heating

Successfully raising and maintaining the temperature of the vacuum manifold is critical to create a photo-cathode layer on the tile window. Cesium is solid at room temperature, so it must be heated to a gaseous state to travel from the Cs source to the tile. Additionally, gaseous cesium will condense on cold surfaces, so every surface the cesium sees on its way to the tile window must be held at a steady temperature of ideally at least 150C.

It is important for the temperature to be steady and uniform to prevent the occurrence of cold spots. Cold spots may appear in the manifold where heat is applied disproportionately. They are difficult to locate and may accumulate condensed cesium, decreasing the likelihood of gaseous cesium reaching the tile.

The majority of our manifold is heated with heating cord coiled around the tube. Each section of cord corresponds to a particular zone of the manifold. Each zone has thermocouples secured at critical junctions, as well as a single control thermocouple (see Fig 6). Zone 1 and Zone M were heated by lamps instead of heating cord, and the temperature of Zone M is controlled manually rather than with a control thermocouple.

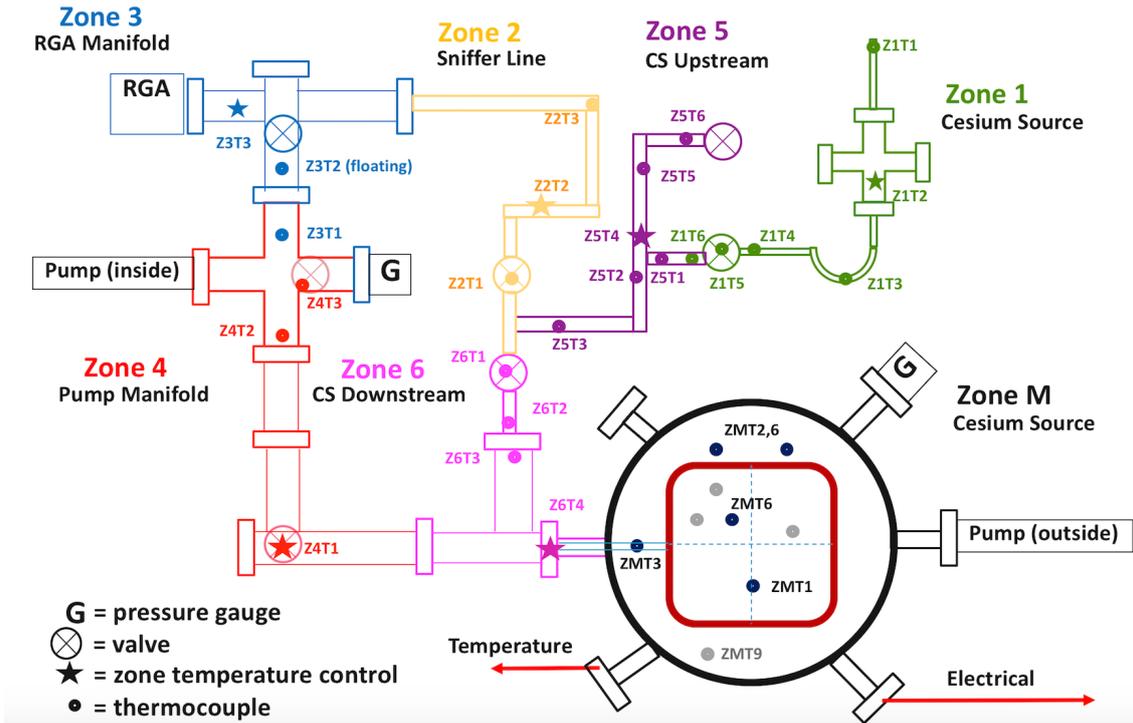


Figure 6: Diagram of the seven heating zones. Each zone has thermocouples at critical junctions, marked on the diagram by circles, as well as a single control thermocouple marked by a star. Zone M is controlled manually rather than by a control thermocouple.

3.1 Thermocouples

To measure the temperature of our system we used thermocouples. Thermocouples produce a temperature-dependent voltage between two wires of different metals.

3.1.1 Single vs Differential

Thermocouple measurements can either be single ended measurements or differential measurements. Single ended measurements can be made when the thermocouple junction is insulated from ground. In instances where this is not possible, such as the thermocouples in Zone M that measure the temperature of the vacuum vessel and tile fixtures, differential measurements are made instead.

3.1.2 Type

We used two types of thermocouples, E and K. In hindsight, it would have been easier to use exclusively one type. Each type of thermocouple has a different set of constants associated with its unique voltage-temperature curve, and these constants are incorporated into our python computer code. Having different types of thermocouples made our system less flexible, and our code more susceptible to bugs, as thermocouple voltages have to be specified as type E or K before their voltages can be interpreted as a temperature. If we added, removed, or switched thermocouples, we had to change the thermocouple type associated with that thermocouple's DAQ channel.

3.1.3 Cold Junction Adjustment

The temperature measured by the thermocouple must be referenced against a known temperature to obtain the true temperature of the junction. The known temperature, also called the cold junction temperature, is measured using a separate sensor. The cold junction temperature is kept relatively steady, and compensates for temperature variation at the junction block [3].

3.1.4 Constraints

The first thermocouples we attached had plastic insulation. Unfortunately, at high temperatures this insulation melts off. The thermocouples then come into contact with ground, which compromises the single ended measurements. Additionally, the adhesives we used to attach the initial thermocouples became ineffective at high temperatures, resulting in thermocouples floating in ambient air. We transitioned to using thermocouples with ceramic insulation attached with cement.

3.2 Recipe for Altering Thermocouples

Due to the complex nature of our heating system, it can be tricky to remove, add, or switch thermocouples. Here is a general checklist that can be used to avoid common mistakes and bugs.

3.2.1 MargpiMux

The python file `margpiMux.py` is located on `pi@thermal` in the `~/MargCode` directory. `MargpiMux` records the temperature output of the thermocouples in a text file named `temprun0.txt`. Each row of the file contains the thermocouple outputs in the order they are processed within `margpiMux`, and a date/time stamp. The columns are delineated with commas and each row is separated in time by three seconds. Within `margpiMux` there are four arrays, accounting for different types and locations of thermocouples.

If you are adding or removing a thermocouple, identify within which array the thermocouple belongs (for example, if it's a type E thermocouple located on the X4 DAQ, then it belongs in the array named `thermoChannelE_X4`). Then, identify the channel number corresponding to the physical location of the thermocouple on the DAQ. Append the correct array in `margpiMux` to include or remove this channel number. If you are altering which thermocouple is the absolute measurement for the cold junction adjustment, then edit the numbers associated with `calChanX4` or `calChanX5`.

3.2.2 Thermocouple Index

The text file `TC_index_es.txt` is located on `pi@thermal` in the `~/MargCode` directory. The thermocouple index contains attaches the information associated with a given thermocouple (name, location on manifold) to its location on the `margpiMux` output file `temprun0.txt`. The index contains as many columns as thermocouple outputs, and two rows. The first row is a list of labels delineated with commas, and the second row is a list of descriptions of the locations of thermocouples on the manifold, also delineated with commas. For example, the first temperature output on the `temprun0.txt` file is `Z6T2`, which is "CF to VCR adapter tubulation", so the first entry in the first row is `Z6T2` and the first entry in the second row is "CF to VCR adapter tubulation."

Look at the `margpiMux` code to identify which temperature output your thermocouple is. The thermocouple readings are grouped on `temprun0.txt` according to the array they belong to, as described in the previous section. If you are adding a thermocouple, then insert the new thermocouple information into the thermocouple index in the appropriate location. If you are removing a thermocouple, then delete that thermocouple's information in the index.

3.2.3 Liveplotter

The python file `liveplotter.py` is located on `margherita@psec2` in the `/local/data2/margherita/margherita_run_scripts/run.live` directory. The `liveplotter` visually displays the thermocouple information in graphs located online at `psec.uchicago.edu/margherita`. Within `liveplotter.py` there are seven arrays that represent the seven heat zones. As described in the beginning of Section 3, a particular zone contains a number of thermocouples located in that section of the manifold. These thermocouples have numbers corresponding to their locations in the `temprun0.txt` file. For example `Z6T2` is the first column in `temprun0.txt`, so the number corresponding to its location is 0. Each zone array contains the `temprun0.txt` numbers assigned to its thermocouples.

Identify which zone your thermocouple belongs to, and its number on the `temprun0.txt` file. Add or remove its `temprun0.txt` number to the `liveplotter` zone array. After this, you will probably need to amend all the subsequent numbers. For example, if you remove the sixth entry in `temprun0.txt`, each subsequent number in the `liveplotter` zone arrays needs to be decreased by 1, such that 7 becomes 6, 14 becomes 13, etc. If you add an entry, you'll need to increment subsequent numbers.

3.2.4 Good Practice to Save Headaches

In a system like ours that uses dozens of thermocouples, there are some easy steps that can be taken to save headaches. Good strain relief is important, especially if it's applied right as the thermocouples are attached to the manifold. Untangling a rats nest of tiny thermocouple wire is not fun!!



Figure 7: I wish I had taken a picture of the tangled knot of thermocouples, but I did not. Instead, here is a stock image that accurately represents how it feels to untangle thermocouples

Additionally, having a good labeling system and attaching labels to both ends of the thermocouples turned out to be incredibly useful. Our system is dynamic, and thermocouple wires are often changing locations. We ran into trouble when we started relying upon memory, outdated charts or even guesswork to try and trace which wires corresponded with which spots on the manifold.

3.3 Temperature Control and Uniformity

Each zone has a thermocouple designated to act as the control thermocouple. Rather than going to a DAQ board, the control thermocouple goes to an Omega controller. Each zone is given a setpoint temperature. When the controller reads the temperature of the junction it accordingly turns on or off power to that zone's heating element to try and reach the given setpoint. Our controller had three parameters: Proportional, Integral and Derivative (PID). The proportional constant accounts for the current difference between the setpoint and measured temperature, the integral for the past differences, and the derivative for the current rate of change of the difference.

The best way to achieve temperature uniformity is with really good insulation. At first we used strips of aluminum foil wrapped around the pipe as insulation. This worked well, but we still had trouble achieving a uniform temperature. There were areas of pipe with large temperature gradients from one spot to the next, and we couldn't get the entire manifold to a satisfactory temperature without raising some segments of pipe to dangerously high temperatures.

To try and alleviate this problem, we switched to fiberglass pipe insulation. This was a much more effective insulation, and we achieved better (although still imperfect) temperature uniformity. Working with fiberglass came with its own difficulties however, and we had to be careful when handling the insulation not to irritate our skin and eyes.

4 Cesium

Once we had a handle on the heating, we deposited cesium into our system. After several unsuccessful attempts and a lot of general bafflement, we succeeded in depositing a layer of cesium on the tile window! We came into the lab after a weekend and found that the tile window had changed to a dark green/blue color (see Fig 8). Soon after, we measured photocurrent from the tile, and confirmed that it was indeed cesium that caused the color change.

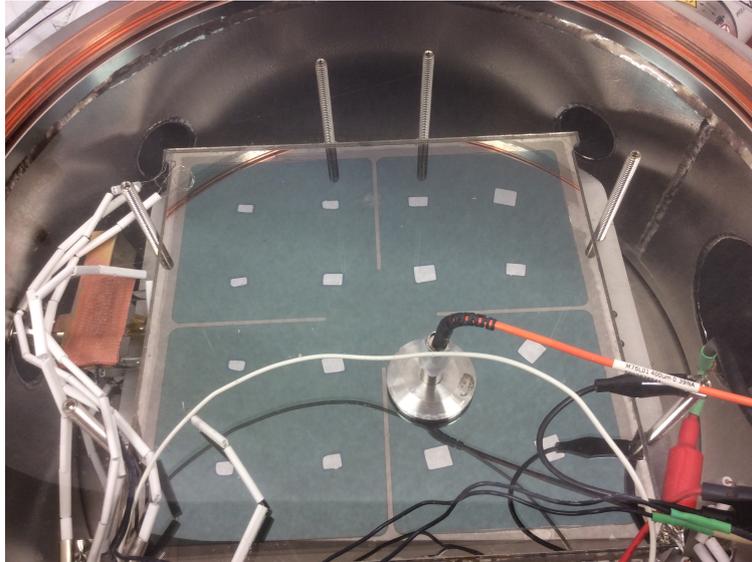


Figure 8: LAPPD tile with cesium deposited on window. The metal rectangles are shims put in place to evenly distribute stress on the glass window

4.1 Voltage Scans and IV Curves

The cesiation happened towards the end of my time with PSEC, so I was only around for some of the preliminary tests we did to measure the properties of our photo-cathode layer.

We started by scanning the tile with positive and negative high voltage and tracking the subsequent current. We found that the best way to get repeatable IV curves was the quickly sweep the current from 0 to the max voltage (1600 for positive, 1900 for negative) and back down, taking about a minute to go in each direction.

We noticed a general downward trend in the current over time (see Fig 9). Additionally, we gently heated and cooled the tile before taking IV curves to try and extract a temperature coefficient (see Fig 10). Unfortunately, during testing we accidentally broke our MCPs, so we have limited temperature data.

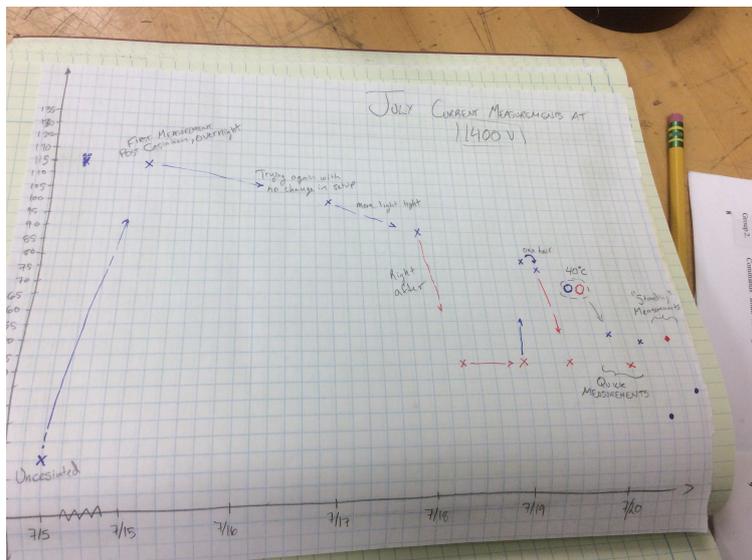


Figure 9: A hand plot of the downward current trend vs time, made by Evan Angelico

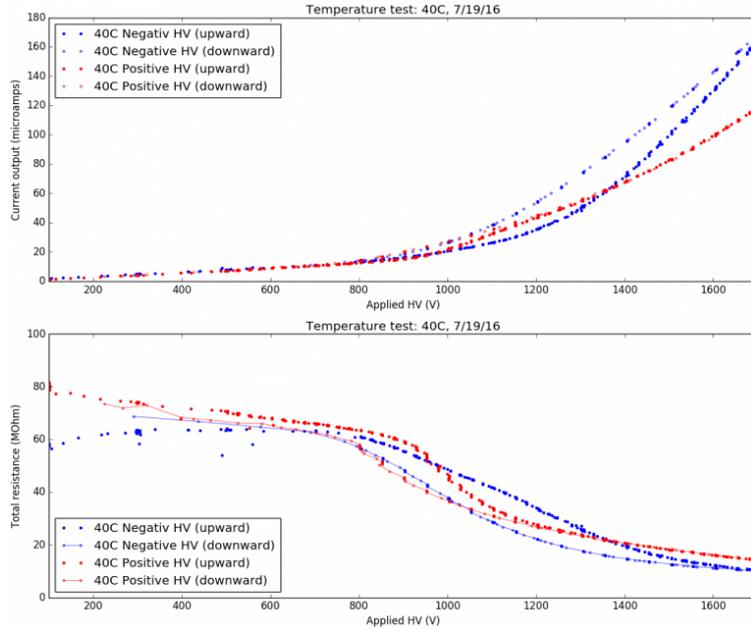


Figure 10: A plot of positive and negative high voltage at room temperature and at 40C vs current

5 Acknowledgements

I began my time at PSEC with essentially no knowledge of photodetectors, vacuum technology, or photocathodes. I entered a lab with a fairly complex system, and joined a team who have been working on this project for years and know the system better than the back of their hand. Luckily for me, every person on the PSEC team was eager, enthusiastic, and patient as I learned the ropes and absorbed the new physics. It's humbling for me to look at this report, knowing that four months ago I would have struggled to understand its contents. Many many thanks to the UChicago PSEC team: Henry Frisch, Bernhard Adams, Andrey Elagin, Evan Angelico, Eric Spieglan, and Hayward Melton. I will keep the lessons you have each taught me for a long time to come.

6 References

1. Frisch, Henry (2016). *The LAPPD Pico-second Photo-Detector* PowerPoint presentation at MIT Lincoln Labs
2. Elagin, Andrey (2016). *An Indium Solder Flat Seal for the Assembly of Large-Area Planar MCP-based Detectors Without Vacuum Transfer of the Window* PowerPoint presentation at ICHEP
3. "Thermocouple." *Wikipedia: The Free Encyclopedia*. Wikimedia Foundation, Web. 15 Aug 2016.