TECHNISCHE UNIVERSITÄT WIEN

DISSERTATION

Cool Science

ausgeführt am Atominstitut

der Technische Universität Wien
Fakultät für Physik

unter der Anleitung von
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durch

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Wien, am 21.04.2020

"The Setesh guard's nose drips."
Teal'c

Abstract

Short and sweet...

Zusammenfassung

Kurz und bündig...

Contents

1. Cathodic Ray Tube Basics

This section features a quick explaination what a CRT is and what it's main components are, followed by a more detailed description on how these components are implemented in the CRT Heerlen D14-363GY, which was used in this project. It ends with a description of the important characteristcs of the CRT and the requirement the theory poses on them.

1.1. Underlying Physics

Wikipedia states: "The cathode-ray tube (CRT) is a vacuum tube that contains one or more electron guns and a phosphorescent screen and is used to display images. It modulates, accelerates, and deflects electron beam(s) onto the screen to create the images."

There are three vital components to accomplish this feat: the electron gun, the electron lens and the deflection plates.

The electron gun extracts electrons from a cathode material, accelerates them onto a perforated anode and thereby produces a free electron beam (see figure 1.1). One important characteristic in the selection of a cathode material is a low work function. The work function denotes the amount of energy needed to extract one electron from the material. The are two ways to overcome this energy barrier in an electron gun, one can either overcompensate it by applying a strong electric field ("field emission", "cold cathode", figure 1.2 a) or one can heat the material until some electrons have enough thermal energy to overcome the energy barrier ("thermal emission","hot cathode", figure 1.2 b). For our CRT, only thermal emission is relevant, more detail on this will be added later along with the description of our cathode's design.

The cathode itself is housed in a so-called Wehnelt cylinder, as the name suggests it is conducting cylinder, which is set to a slightly more negative potential than the cathode itself. This part implements two freatures, firstly it condenses the emitted electrons, leading to a smaller spot size, i.e. making the cathode a more point-like electron source. Secondly it enables us to regulate the beam current, the more negative the Wehnelt potential is, the less electrons are emitted by the electron gun. As we
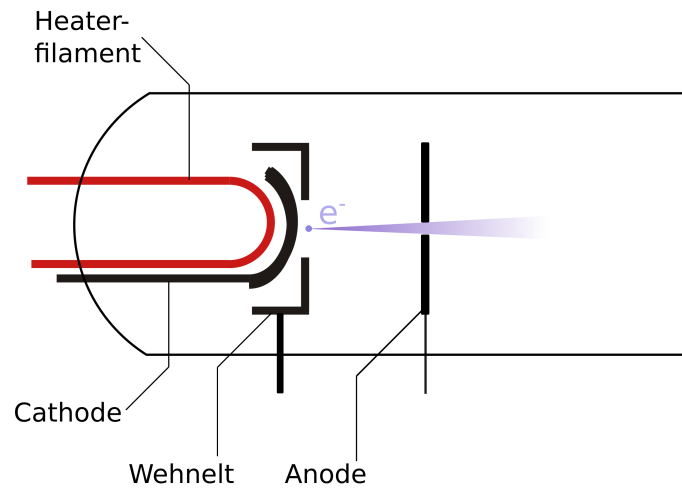
1

April 21, 2020 – 16:58

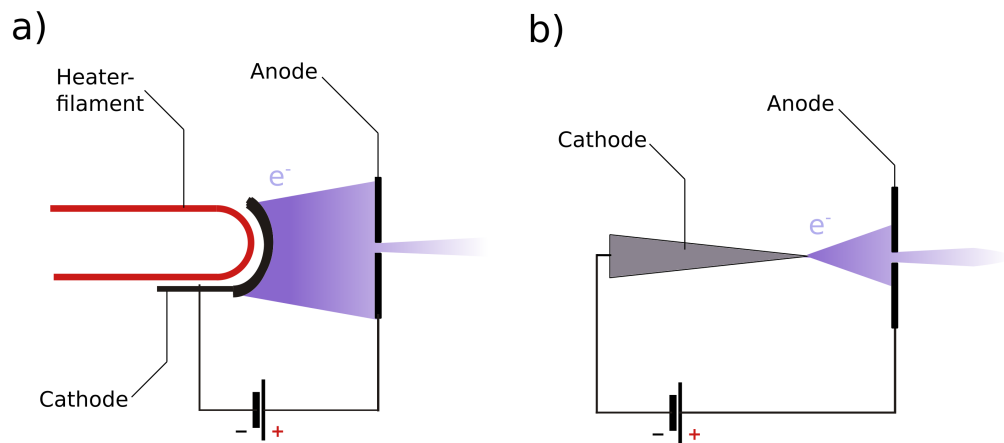**Figure 1.1.:** Schematic of an electron gun

Figure 1.2.: a. Schematic of a hot cathode; b. Schematic of field emission cathode
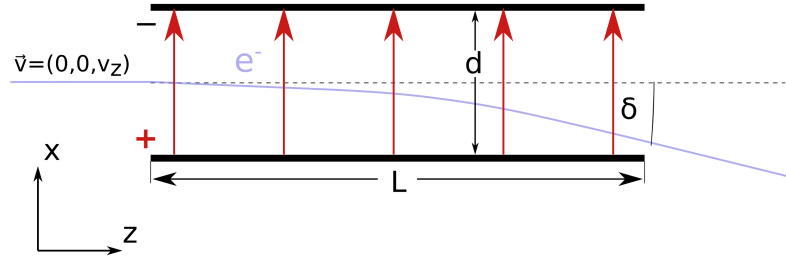
Figure 1.3.: Deflection of an electron beam in a constant electrical field

1 make the Wehnelt potential more positive, the beam current keeps increases and keeps
2 increasing even after it is more positive than the cathode itself. However the spot size
3 reduction is lost in the process, along with the ability to properly focus the beam with
4 the electron optics.

5   The electrons that leave the electron gun are still divergent and need to be focused.
6 For our 2 2 keV electrons it is still possible to use an electro static lens. Cylindrically
7 symmetrical pieces of conductor, like rings and tubes, can be set to an electrical
8 potential and act as a lens for the electrons. By combining several of them, one can
9 (theoretically) engineer an electro-optical system with any combination of desired focal
10 lengths f_1 and f_2. The field of this system is simply governed by Laplace's equation in
11 cylindrical coordinates:

$$0 = \frac{1}{r}\frac{\partial \phi}{\partial r} + \frac{\partial^2 \phi}{\partial r^2} + \frac{\partial^2 \phi}{\partial y^2} \tag{1.1}$$

13 If we take the axis of the beam to be the z-axis, the position of the focal point in the
14 x-y-plane can be shifted using the two pairs of deflection plates, one for the x- and one
15 for the y-direction. The deflection is achived by applying a voltage between the two
16 parallel plates. (see: figure 1.3) In this simple case the deflection angle is approximately
17 [1]:

$$\delta \tan(\delta) \approx \frac{e \cdot U_z \cdot L}{2U_0 \cdot d} \tag{1.2}$$

19   As the angles in question are normally well below 1 degree, everything will probably
20 be easy :)

how does this compare to actual in the tube?

3

1.2. Implementation in the Heerlen D14-363GY

,

This section describes how, the mechanisms described above are implemented in the CRT that was used in this project: the PDS/CRT Heerlen D14-363GY. Figure 1.4a shows an image of said CRT, figure 1.4b shows a schematic depiction. The cathode is not visible, as it is fixed inside the Wehnelt cylinder (1), just a few millimeters from the exit of the wehnelt cylinder the electrons pass through the perforated anode (2) they gain their full final kinetic energy over this short distance. The electrons that go through the perforation and enter the electrostatic lens, have $2\,\text{keV}$ and therefore move at a speed of approximately $0.08\,c_0$. The electrostatic lenses are realized using three conducting rings (3), that are set to the same potential but have varying radii: Each consectutive ring has a smaller radius than the previous one.

Between the electrostatic lens and the deflection plates, there is another aperture (4), which is internally connected to the anode and is thereby kept at the same potential. In our Setup, the deflection plates are not simply parallel but are shaped like funnels (5,7), between the two pairs of deflection plates, we have the final aperture (6), this ones potential can be regulated seperately (usually it's on the same potential as the anode)

It is connected to the glass envelope of the CRT to prevent the glass from charging up and distorting the image. Finally the beam hits the phorsphorous-coated screen which floureces on electron impact.
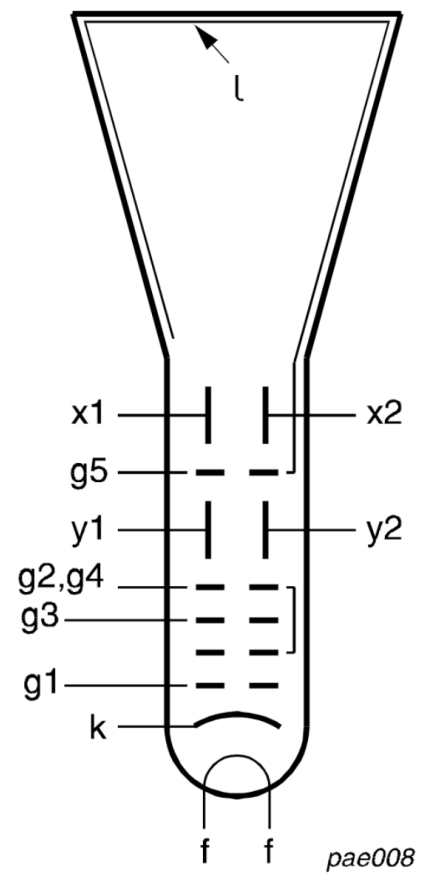
1.2.1. The Cathode

As already mentioned, we are using a hot cathode, where the electrons are exited thermally until some of them acquire enough energy to leave the material. Compared to cold cathodes, which work by field emission, this leads to a broader energy distribution. In fields like electron microscopy, where a high resolution is the goal, this in undesireable, as it leads to some degree of chromatic aberration in the elecron optics, for our purposes, this should not be a problem. On the other hand, hot cathodes normally allow for higher current densities (cite), which is very important to us. The electron current from this kind of emission is described by:[**PowerTubes323**]

$$I = A \cdot T^2 \cdot e^{-b/T} \tag{1.3}$$

Where b is proportional to the the work function of the material, T is temperature

How to properly subfigures?

Insert Image of CRT

cite?

(a) Image picture of the Heerlen D14-363GY

(b) Schematic of the CRT from [2]

Figure 1.4.

and *A* is a material-dependent constant. It is clear from this formula, that a low work function and a high melting point are important characteristics for a good cathode material.

The cathode from one of our Heerlen D14-363GY-tubes has been removed and examined with EDX (Energy-dispersive X-ray Spectroscopy). Nickel, barium, and strontium have been found, which suggests that it is a metal oxide cathode with barium-, strontium-, and possibly aluminum-oxide. This type of cathode is very common in low power electron tubes.

The "Power Vacuum Tubes Handbook" [3] describes a typical oxide cathode as a coating of barium and strontium oxides on a structure made from nickel alloys. Nickel is chosen for it's strength and toughness, which it retains even at high temperatures. These cathodes are normally made by coating a case stucture with a mixture of barium and strontium carbonates (typically 60 % Ba and 40 % Sr), suspended in a binder material and then baking the structure, causing the carbonates to be reduced to oxides.

These metal oxide cathodes normally operate at 700 °C to 820 °C and are capable of average emision densities of 100 mA cm⁻² to 500 mA cm⁻². Still higher peak emissions are possible for shorter periods of time, as already mentioned, one of the advantages of this type of cathode is it's high emission current capability compared to cathodes made from other materials. Downsides to this cathode type are its greater susceptibility to so-called oxygen poissoning and to ion bombardement. The literature therefore recommends to avoid prolonged exposure to oxygen, this will be expanded upon in section (reference) . Also the material from the oxide cathode will evaporate during the lifetime of the tube and will travel to other parts of the tube. The literature (also from [3]) therefore also advises against exceeding the design value for the heater voltage, as this reduces the lifetime of the cathode significantly. (however during the course of our project, we did drive the cathode with higher heater voltages on various occasions in order to increase the available beam current)

insert ref to sec on CRT handli

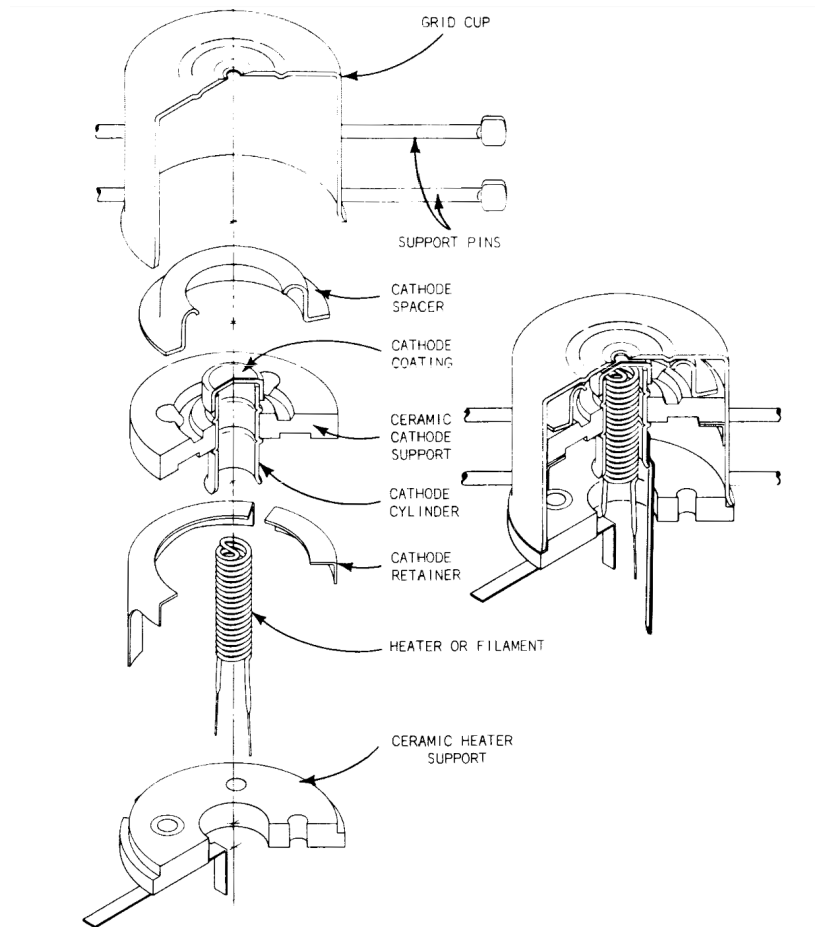**Explaination la cathode**

1.2.2. Cathode Layout

Figure 1.5.: Schematic of the layout of a typical metal oxide cathode

Appendix

A. Appendix A

A.1. Source Code

Here is some source code added with the lstlisting package. With

$£\vdots£$

you can insert vertical dots to truncate code.

```
/*++++++++++++++++++++++++++++++++++
+              Awesome source code           +
+                  TU Wien 2018               +
+                 Thomas Weigner              +
+           weigner.thomas@gmail.com          +
+                    main.cpp                  +
+                   vers  3.4.1                +
++++++++++++++++++++++++++++++++++++*/

#include <header.h>
//−−−main program
int main(){
//−−−declare stuff and initialize things
⋮
//−−−−−−−generating polynom for vertical transport
Poly polArray[5];           //Creating a polynom object array with the default constructor
double vMax = 2.0;          //maximal velocity
⋮
```

A.2. Matlab2Tikz

Matlab to Tikz a is a very power full script to translate a Matlab figure into Tikz and
Pgf code. After creating a file containing the code with this Matlab script one can do

8

1 fine adjustments directly in the code. If you are not already using it you should go
2 and check it out.

9

Todo list

draft - v1.0   April 21, 2020 – 16:58

List of Figures

draft - v1.0   April 21, 2020 – 16:58

List of Tables

Acknowledgements

Thanks to ...

References

[1]   Wolfgang Demtröder. *Experimentalphysik 3*. Springer-Lehrbuch. Berlin, Heidelberg: 2
      Springer-Verlag Berlin Heidelberg, 2009. Chap. 2.6.1.   3

[2]   Frank Philipse. *D14363GY123*. URL: https://frank.pocnet.net/sheets/186/d/   4
      D14363GY123.pdf (visited on 03/10/2020).   5

[3]   Jerry C. Whitaker and Fla. [Verlag] CRC Press Boca Raton. *Power vacuum tubes*   6
      handbook. Third edition. Electronics handbook series. Boca Raton, FL: CRC Press.   7
      Chap. 3.5.2.1.   8