Examination of the 7th November 2017

Lectures of N. Delerue

All documents allowed

Reminders

The Richardson formula given in the lecture reads as follow:

$$J = A_k T^2 e^{-\frac{W}{k_B T}}$$

$$A_k \sim 1.2 \times 10^6 Am^{-2}K^{-2}$$

The value of the Boltzmann constant is 8.6 10^{-5} eV.K^{-1} .

A 500nm photon has an energy of 4x10^{-19}Joules.

The Child-Langmuir formula given in the lecture reads as follow:

$$J = KS\frac{V_d^{3/2}}{d^2}$$

$$K = 2.33 \times 10^{-6} A.V^{3/2}$$

J is the current, s the area, Vd the potential and d the distance.

1 Coulomb = 6.28 10^{18} electrons

1. Lecture questions (9 points)

1.1. Cite three processes through which a neutral atom in gaseous state can become ionised and discuss their relative cross section. (4/20)

Three processes:
- Impact ionization
- Photo ionization
- Charge exchange

Impact ionization has the highest cross section, photo ionization the lowest.

`Note: Several students gave a description of the type of ion sources or the processes to extract electrons from a solid cathode. This was not accepted.`

1.2. Describe the main elements (at least 5) of an Electron Cyclotron Resonance (ECR) source. (5/20)

Some sub-systems:
- Cathode
- Gas/gas inlet
- Plasma chamber
- RF
- Focussing coils
- Beam extraction
- Vacuum system

`This question was usually well understood.`

2. The PHIL and CLIO accelerators (11 points)

2.1. The accelerator PHIL uses an RF gun as electron source whereas the CLIO accelerator uses a thermionic gun. Compare the properties of the electrons produced by these sources. Your comparison should at least comment on the following points:

- Electrons energy and energy spread?

A photoinjector has a lower energy spread than a thermionic gun. The energy of the electron at the exit of a RF photoinjector will be a few MeV against a few dizain keV at the exit of a thermionic gun.

`Note: the laser intensity and the cathode temperature do not control the particles energy`

- How to produce high charge bunches? How easy is it in each case?

In the case of a thermionic gun the cathode temperature can be increased. In the case of a photoinjector this requires a higher laser charge.

`Note: A higher electric field increases the charge only marginally.`

- How to go to a high repetition rate? How complicated is it in each case?

In the case of a thermionic gun this requires a higher modulation frequency of the of cathode grid. In the case of a photoinjector this requires a higher repetition rate laser.

- For these two sources, explain how the bunch length can be controlled? (4/20)

In the case of a thermionic gun this requires to change the duration during which the cathode grid is open. In the case of a photoinjector this requires to change the laser pulse length (sometimes this can be done by changing the compressor).

2.2. Let's consider a photoinjector using a laser with a power of 1MW during 1ps. The laser radiation is emitted at a wavelength of 250nm. The cathode has a quantum efficiency at 250nm of 10^{-4}. What is the charge of the bunch produced by each laser pulse? (2/20)

250nm => $8\ 10^{-19}$J. `The value for 500nm was given in the reminders.`

1MW during 1ps = 10^{-6}J.

$10^{-6}J/8\ 10^{-19}J = 1.25\ 10^{12}$photons

$1.25\ 10^{12}$ photons x QE = $1.25\ 10^{8}$ electrons ~ 25pC.

`This question was usually poorly understood: the conversion from joules to number of photons was usually incorrect despite the information being given in the reminders.`
`Some students misunderstood the meaning of the QE: it is not an attenuation of the incident power. QE corresponds to photons that are lost (because they aren't absorbed).`

2.3. Now let's consider a thermionic gun operating with a titanium cathode (let's assume that the cathode has a work function of 4.3eV). The size of the cathode is 5mm x 5mm, it is at a potential of 50kV with a 100mm gap between the cathode and the anode. It is heated to a temperature of 2700K. What is the current produced by this cathode? Suggest a mechanism that could be used to limit the cathode emission to 100ps at a time. What would be the charge emitted per bunch in that case? (3/20)

T=2700K; W=5eV; 25mm^2; => J=97mA.

The expected current is 6mA, that is 3.8 10^6 electrons per 100ps pulse.

The emission can be limited by a negatively charged grid near the cathode.

As we will see in the next question, in fact this theoretical value is not reached due to space charge limitation.

Several students applied incorrectly the Child Langmuir law here. What we want at this question is to know the thermionic emission, not the space charge limitation.

2.4. To increase the emission one could increase the operating temperature of the thermionic gun described above. What would be the limit current that could be reached by increasing the temperature? Why? (2/20)

Child-Langmuir law:

S=25mm^2; Vd=50kV;d=100mm

The limit current is 65mA.

Very few students attempted this question.