Role of CF4 in gas amplification in gems

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(For Gems for CMS collaboration)
Outline

- A bit of discussion on CF$_4$
- Gain in case of single gems for CF$_4$ mixtures
- Loss rates in case of single gems
- Gain in **triple gem** and comparison with data

RD-51 mini week, November 2011
The Gas called “\( \text{CF}_4 \)”

- A Fast gas because of large electron scattering cross-section > 0.5 eV. This lowers the energy of the electrons in the mixture to less than 0.5 eV. (Effectively acting like a pillow rather than a hard surface)

- At this energy the cross-section is less in case of Argon.

- Hence the mean free path is large, and so an increase in drift velocity over a range of \( E/p \) values.
The Gas called “CF$_4$”

- 4 fundamental vibrational modes
  - Symmetric stretch (0.112 eV), symmetric bend (0.054 eV)
  - Asymmetric stretch, (0.157 eV) Asymmetric bend (0.078 eV)
- Studies have revealed strong vibrational excitation by electron impact below 2.0 eV. (We know it is a fast gas !)
- Excitation energy of asymmetric stretch very near the Ramseur minimum in momentum and electron scattering cross-section at 0.16 eV.
Electron scattering cross section

One can see the Ramseur dip at 0.16 eV

Momentum transfer cross section

Attachment in CF$_4$

- Resonant electron attachment to CF$_4$ occurs mainly in 6-8 eV via two negative ion states.

- Ground state of CF$_4^-$ at 6.8 eV producing F$^-$ and CF$_3^-$ via complementary channels.

$$\text{CF}_4^- \rightarrow F^- + \text{CF}_3^-$$

$$\text{CF}_4^- \rightarrow F^- + \text{CF}_3^-$$

F atoms produced
First electronically excited state of $\text{CF}_4^*$ at 7.6 eV producing only $\text{F}^-$.

$$\text{CF}_4^* \rightarrow \text{F}^- + \text{CF}_3^*$$

- An interesting thing to note is that $\text{CF}_4^-$ not observed in gas phase as, only seen in van der waals clusters of $\text{CF}_4$, where auto-detachment is slow.
Ionization Of CF$_4$

Dissociative Ionisation – dominant in CF$_4$ above 30-35 eV.

\[ e + CF_4 \rightarrow CF_3^+ + F + 2e \]

This being the dominant reaction

Fluorine again
A look at the partial ionization cross section for production of $\text{CF}_3^+$ and other radicals!

Clearly $\text{CF}_3^+$ cross-sections are a factor of $\sim 10$ greater.

Important observation being that below ~16.2 eV dissociation into neutrals dominates, whereas at higher energies, dissociative ionisation takes over. (about 30-35 eV)

The threshold for generating neutral fragments is about 12.5 eV.
This value being lower than the ionization potential of CF₄ (16.2 eV), neutral dissociation dominant at low electron energies.
At energies below neutral dissociation threshold, dissociation occurs via electron attachment.
So
  Electron attachment < neutral < ionic 

Increasing electron energy
Total Electron attachment cross section for CF$_4$


Simulated attachment in case of single gems in Ar (45)/CO$_2$(15)/CF$_4$(40) gas mixture
Penning transfer?

- Looks unlikely from the preceding discussion.
  - High ionization energy of **16.2** eV, which is also higher than the ionization energy of Argon !
  - Hopefully no penning transfer from Ar to CF$_4$ .
  - No stable excited state of CF$_4$
  - So penning transfer from CF$_4$ to CO$_2$ unlikely
  - Any data for CF$_4$ in single gems?

- As a conclusion, we can take home the fact that gain should be lower in case of CF$_4$ mixture
The effective gain in case of single gem for Ar/CO₂/CF₄ mixture is shown for varying gem potentials and penning parameters.

The parameters in simulation being

- Drift field – 2 kV/cm
- Induction field – 3 kV/cm
- Drift/induction space – 3/2 mm
Comparison of effective gains

The value of gain in Ar/CO$_2$/CF$_4$ is compared with Ar(70)/CO$_2$(30) (which compares well with the data).

The penning parameter chosen is 0.6.

Clearly one can see a reduction of in gain in case of CF$_4$ mixture.
Possible reasons

- Less Argon would mean less ionization electrons and less CO$_2$ which would mean less penning transfer.
- Also presence of both CO$_2$ and CF$_4$ would lead to an increase in attachment loss.

The loss rate plots for both the primary and secondary electrons are shown as:

- Attachment loss rate
- Geometric loss rate
- Overall loss rate

The values of the loss rate are compared with Ar/CO₂ mixture.
Ar/CO₂

A much higher value seen in CF₄ mixture (About a factor of 6-7 higher)

Ar/CO₂/CF₄

Attachment Loss rate for primaries

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Almost the same for both gases, as expected.
Overall Loss rate for primaries

As a result, the overall loss rate is higher in the case of CF$_4$ mixture.
Attachment rate for secondary electrons higher in case of CF$_4$ mixture.

**Ar/CO$_2$**

**Ar/CO$_2$/CF$_4$**
However, the geometric loss in case of CO\textsubscript{2} is a bit on a higher side (diffusion)
Surprisingly, the overall loss rate is quite the same for both the mixtures.
Plotting the electron endpoints in the gem, gives us a good picture of the geometric loss in gems.
So how fast?

- Plotting the time taken by the electrons to reach the anode in case of Ar/CO$_2$ and comparing the result with Ar/CO$_2$/CF$_4$ should give an indication.

- We fit it with a Gaussian function to get an estimate of the time resolution!
Clearly, the mean of the time taken reveals the fact that CF4 mixture is faster than general CO2.

\[ \sigma = 1.194 \]

\[ \sigma = 0.6289 \]

Clearly, the sigma value shows the resolution to be better in case of CF4.
The gap for the triple gem were:
- Drift space: 3 mm
- Transfer-1 space: 1 mm
- Transfer-2 space: 2 mm
- Induction space: 1 mm

The value of the various fields and potentials were taken from the group.
Gas mixture was Ar(45)/CO$_2$(15)/CF$_4$(40)
However we divided the triple gem into three separate single gems, and then multiplied the gain in these three single gems to get the total gain.

\[ G_{\text{Total}} = G_1 \times G_2 \times G_3 \]
The simulated gain seems to be in good agreement with the experimental gain. (Laura, Michal, Andrey)
• The simulated gain matches quite well for penning parameter of 0.60.
• The transfer rate is 0.55 for 15 % CO$_2$ from Ozkan’s paper. So we are in good shape! (No role played by CF$_4$ in penning transfer)
BUT...

- However when we simulate the gain in a triple gem structure, we are off-track!
- As an example, for HV supply of 4200, we get a value of ~1000 which is less compared to the experimental value of ~3000.
- Hopefully, we will get it sorted out!
Dangers of Using CF$_4$

- CF$_4$ is an active source of reactive neutral and ionic fragment atoms and molecules (especially neutral F atoms)
- Neutral F atoms are active species in etching process.
- Hopefully they don’t eat the detector!

Cross-section for production of fluorine on impact of electron with CF$_4$

However …

The electrons are not reaching that high energies in the Ar/CO$_2$/CF$_4$ Mixture in Gem detectors sufficient to Produce enough fluorine to damage the detector that fast!

Mean energies of \(~ 6 \text{ eV}\).

A fact which ageing studies on gems operated with CF$_4$ have shown

Claims that the Detector will work for 10 years
Thank you

I would like to thank Rob Veenhof, Heinrich Schindler, Tania Moulik and Stefano Colafranceschi for their help

I would also like to thank RD51 for their support