Estimation of the Electron Temperature in a Li_2CO_3 Ablative Capillary Discharge

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Contributions:

- Measurements : TU Graz
- Data processing : CTU Prague
- Temperature estimation (IONMIX) : IPP CAS Prague
- Collisional-radiative model (CADILAC2) : TU Graz
- MHD model (NPINCH) : ITEP Moscow

Instantaneous spectra

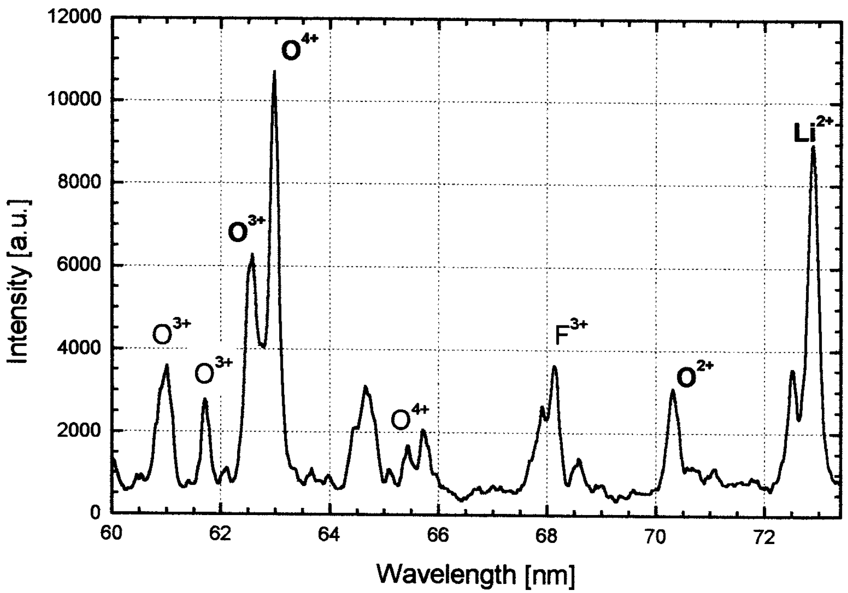
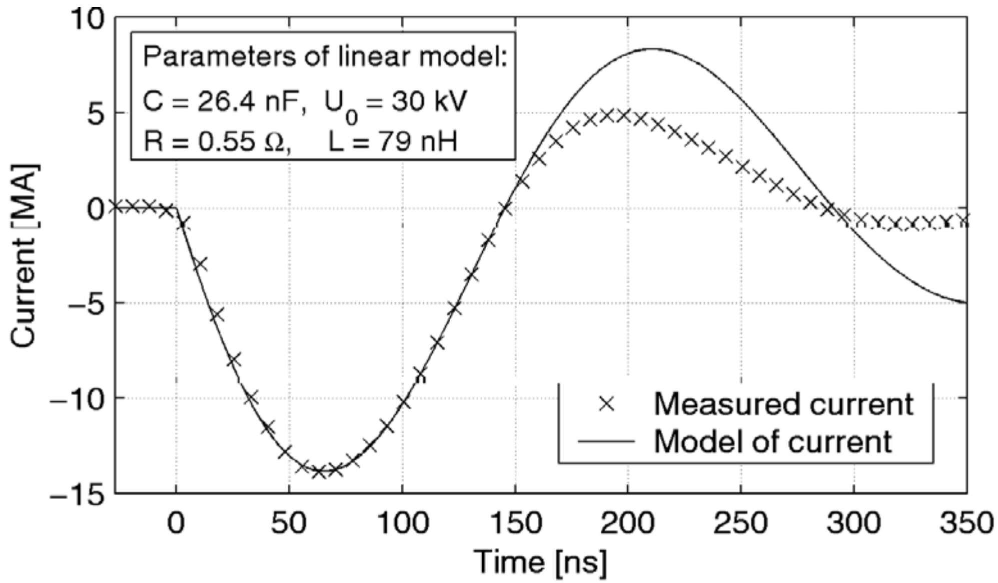


Fig. 1: Instantaneous XUV spectrum for delay time 132 ns

- Li_2CO_3 capillary discharge
- records at various delay times with gating interval 5 ns
- oxygen, lithium and fluorine ions identified

The waveform of the discharge current



- Time dependence of measured circuit current
- Approximation of under-dumped serial RLC circuit

Fig. 3 : Discharge current measured and modeled

Spectra measurements in multiple shots

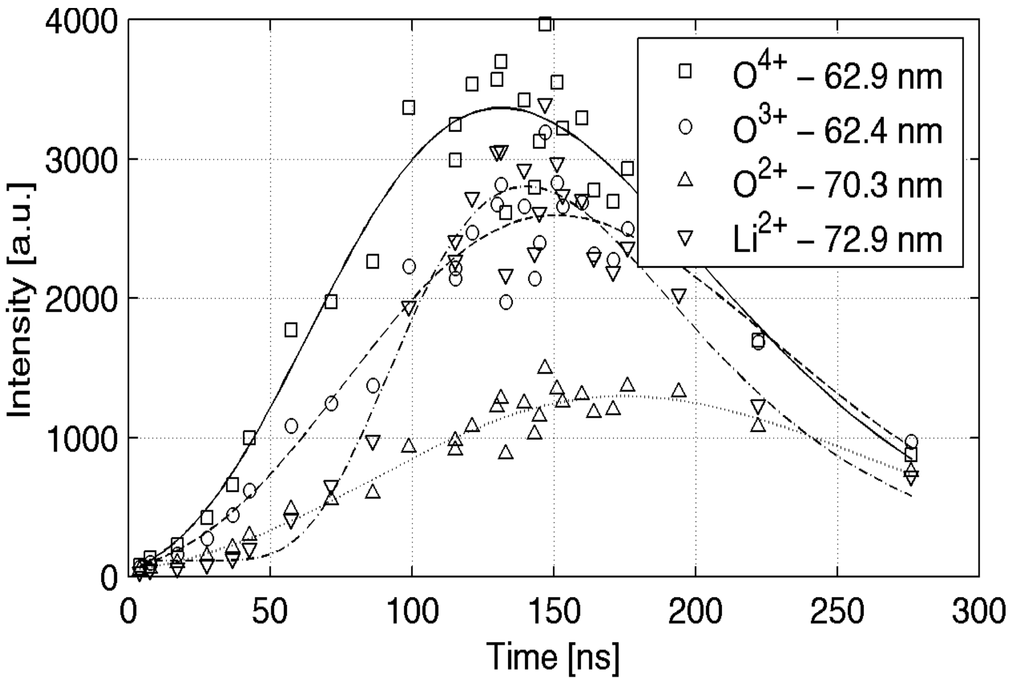
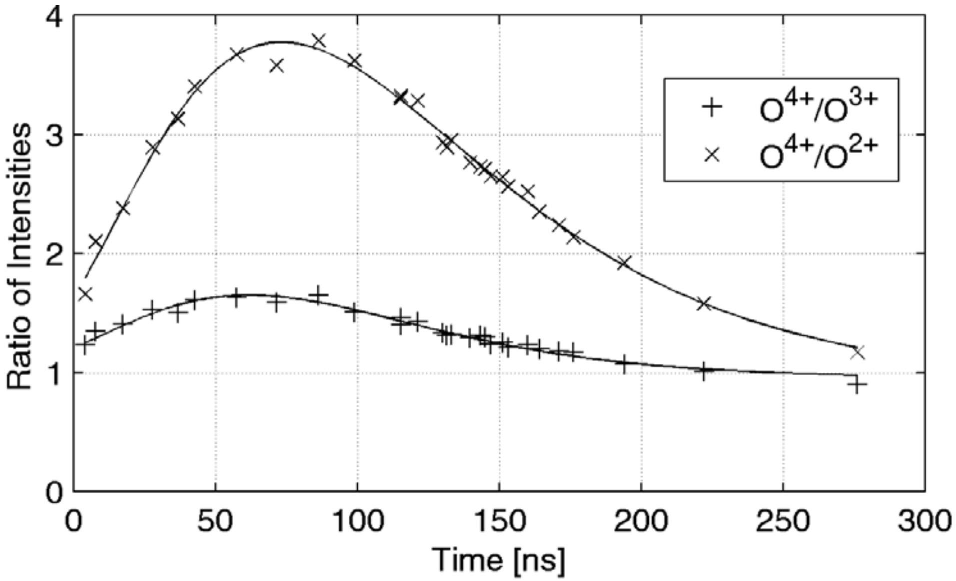


Fig. 2 : Time dependence of selected spectral lines intensities

- The lower is the ionization state the more delayed is the peak value
- All the peaks of spectral lines are well delayed after the first discharge current maximum

Spectral line intensity ratios



- The ratios of the spectral line intensities of O^{4+} (63.0 nm) to O^{3+}(62.5 nm) and O^{4+}(63.0 nm) to O^{2+}(70.3 nm) show that the peak electron temperature is reached before discharge current maximum

Fig. 4 : Time dependence of ratios of intensities

Line intensity evaluation

Spectral line intensity I_{nmjk} , corresponding to the transition from the quantum state n to m of the j-th type ion of the atom k :

$$I_{nmjk} = h\nu_{nmjk} A_{nmjk} N_{njk}$$

$h\nu_{nmjk}$ *is* photon energy, A_{nmjk} the spontaneous decay rate, N_{njk} the upper level population density.

Temporal dependence of the relevant upper level populations

$$N_{njk}(t) = f_{jk}(t)\, f_{njk}(t)\; N_k \, ,$$

$f_{jk}(t)$ and $f_{njk}(t)$ are the ionization and energy level population fractions. N_k is the number of nuclei k .

The ratio of spectral line intensities

The ratio of two spectral lines intensities

$$R = I_{nmjk} \;/\; I_{n'm'j'k'}$$

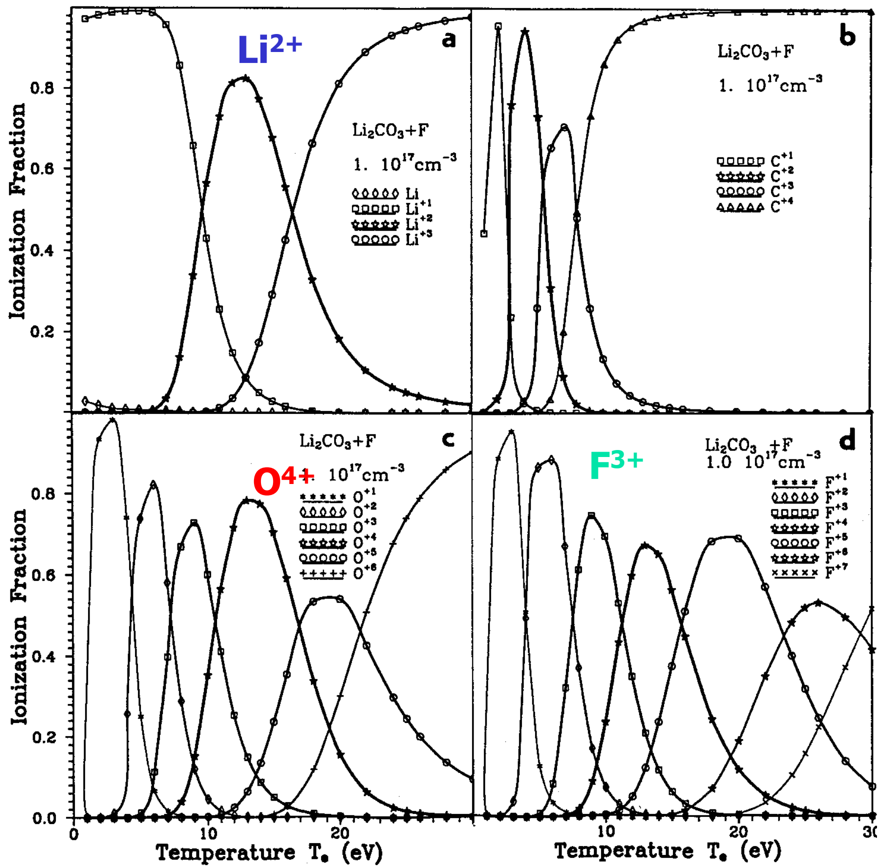
For O^{4+}(λ = **62,97 nm)** and O^{3+}(λ = **62.54 nm**), ***k* = *k'* = oxygen,** ***j* = 4, *j'* = 3,** $\nu_{nmjk} / \nu_{n'm'j'k'} = 1$ and $A_{nmjk} / A_{n'm'j'k'} = 0.449$.

If, moreover the ratio of **energy level population fractions.** $f_{njk}(T_e) / f_{n'j'k'}(T_e) = g_n / g_{n'} = 3/4$ be presumed

$$R(t) = \frac{I_{nm4,oxygen}}{I_{n'm'3,oxygen}} \cong 0.337 \frac{f_{4,oxygen}(T_e(t))}{f_{3,oxygen}(T_e(t))}$$

IONMIX code

Non-LTE ionization fractions evaluation

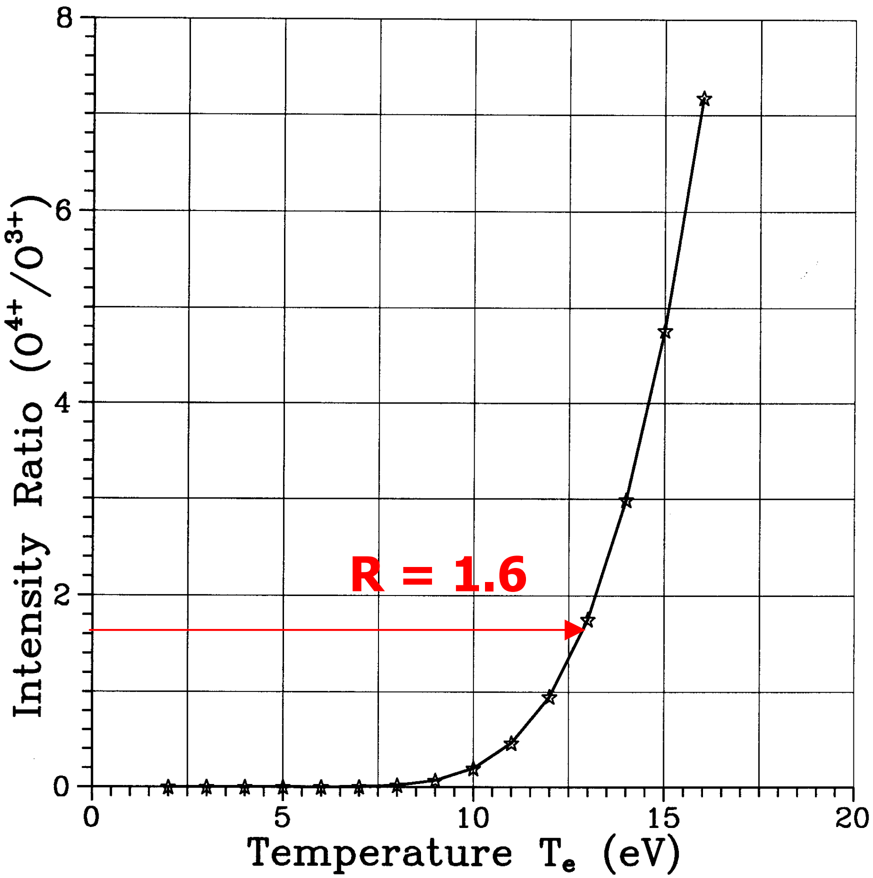


- Steady - state ionization fractions for material ablated from the **Li_2CO_3** capillary wall.

- The ratio of atomic concentrations:
  Li : C : O : F = 2 : 1 : 3 : 0.001

- The ionization fractions for Li, C, O, F were evaluated for **T_e= 1÷30 eV** and total density **N_{tot} = 10^{17} cm^{-3}** .

The ratio R (predicted)

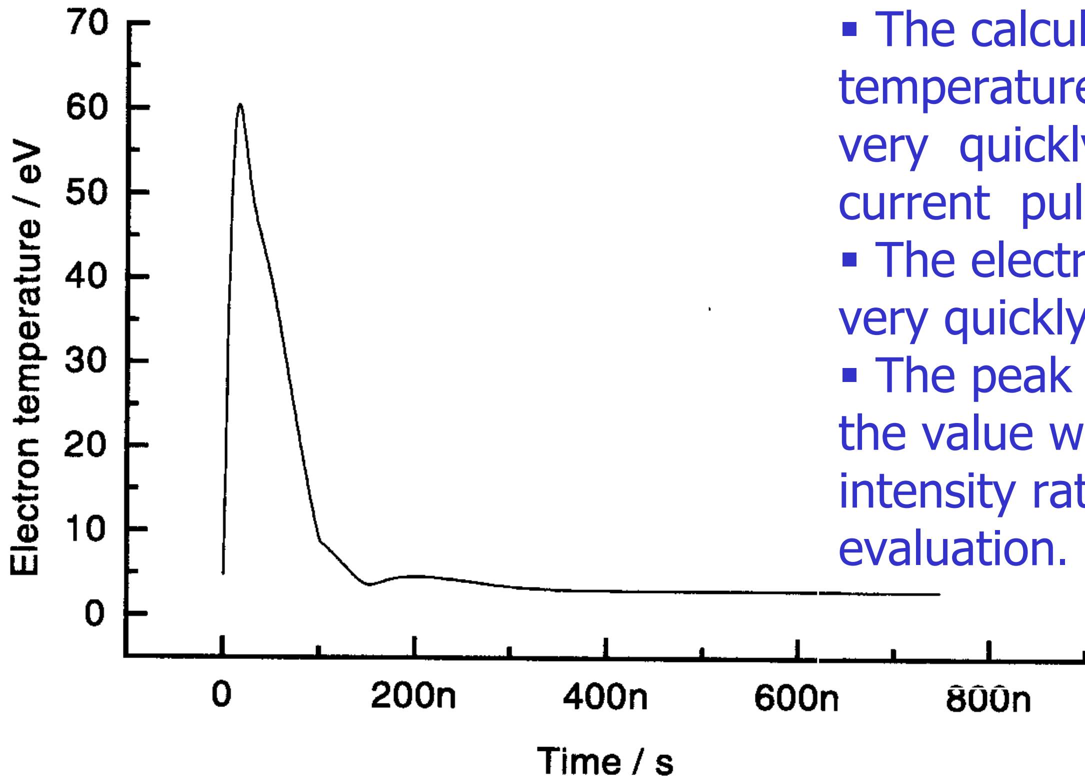


- The **ratio R is less than** 1, if the plasma electron temperature **T_e is smaller than 12 eV.**
- For temperatures **higher than 10 eV** the value of R is a rapidly **increasing function of T_e**
- If we take into account the experimental value of **R = 1.6** we may estimate peak electron temperature as **T_e =13 eV for N_{tot} = 10^{17} cm^{-3}**

CADILAC2 code

Zero-dimensional time dependent collisional-radiative model

- Dynamics of **lithium** atoms only
- **Circuit** equations included

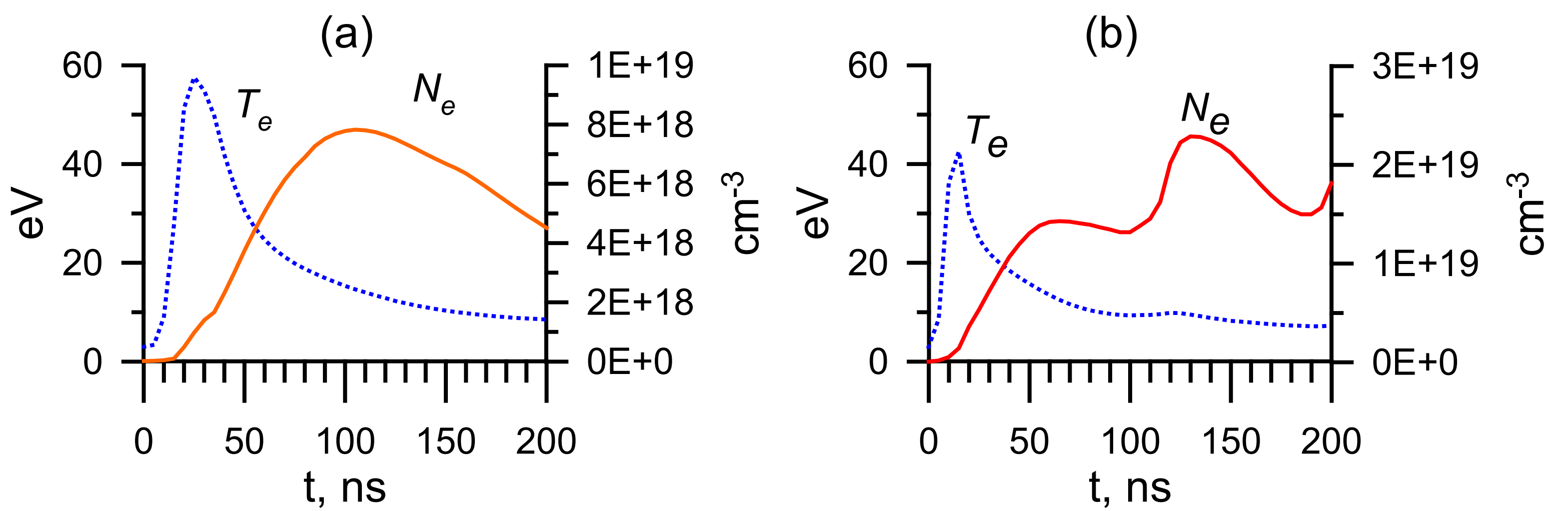


- The calculated **peak value** of lectron temperature **T_e ~ 60 eV** is achieved very quickly at leading edge of the current pulse.
- The electron temperature decreases very quickly to the value about **15 eV** .
- The peak temperature is higher than the value which follows from the intensity ratio measured and **IONMIX** evaluation.

NPINCH code

Two-temperature one-fluid **MHD** model

- Ablation of capillary is included
- Ionization equilibrium is presumed
- Current pulse shape follows the experiment
- The instabilities leading to **MHD turbulence** judged
- Peak plasma **electron temperature 40 ÷ 60 eV** achieved at time **15 ÷ 25 ns**
- Comparison of results **without and with MHD turbulence**, a) and b) resp.



Conclusions

- The highest and lowest experimental values of the intensity ratio R=3.5 and R=0.8 according to the **IONMIX** code correspond to the temperatures 14 eV and 11.5 eV , respectively.
- The peak values of the electron temperature, evaluated according to the **CADILAC2** code and **NPIC- MHD** code are higher than the value which follows from the measured intensity ratio.
- The discrepancy may be explained by a **steady-state presumption**, used in the IONMIX code, and probably **not applicable for the experiment.**
- Nevertheless, at the later time (t > 100 ns) when the plasma is dense and temperature changes are rather slow, the **computer code predictions of temperature** as well as **the estimations based on the intensity ratio** measurements correspond each other.

References

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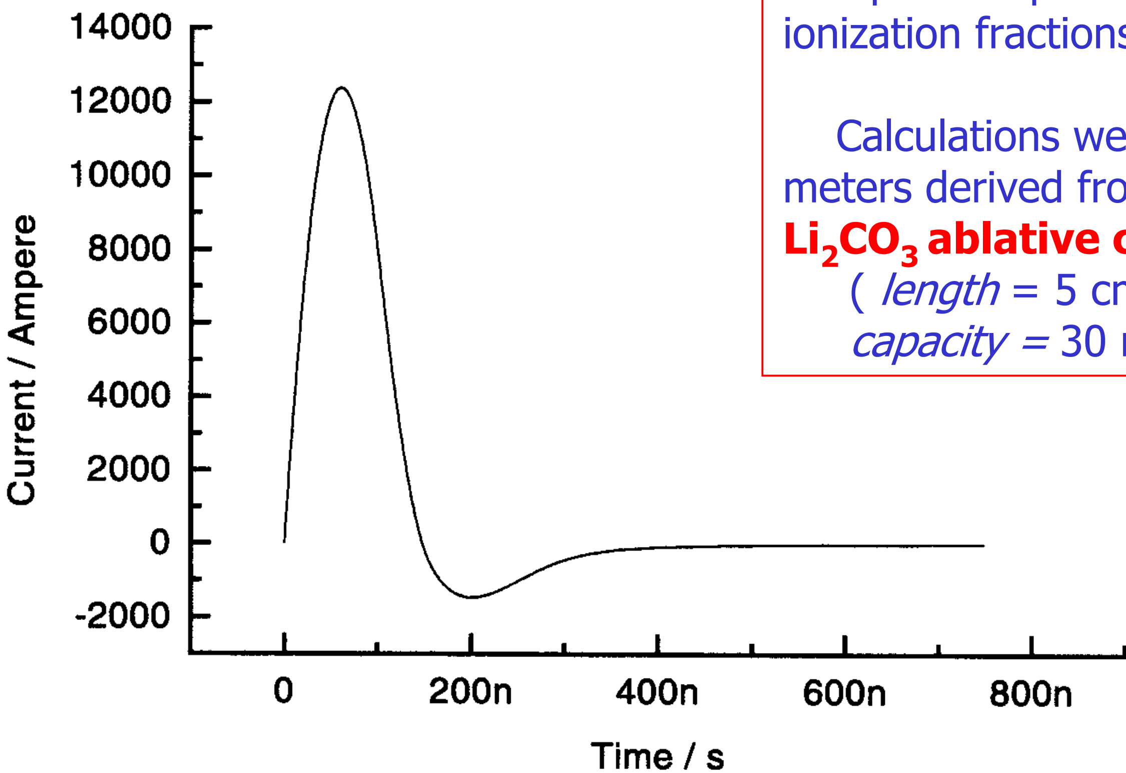
The goal Opening topic

- **Overview of the experimental data**
- **Theoretical background**
- Non-LTE ionization fractions evaluation
- Zero-dimensional collisional-radiative model
- Magnetohydrodynamic model
- **Conclusion**
- **References**

CADILAC2 code

collisional-radiative Zero-dimensional model



Zero-dimensional collisional-radiative model was used to calculate simultaneously the plasma parameters, population and ionization fractions.

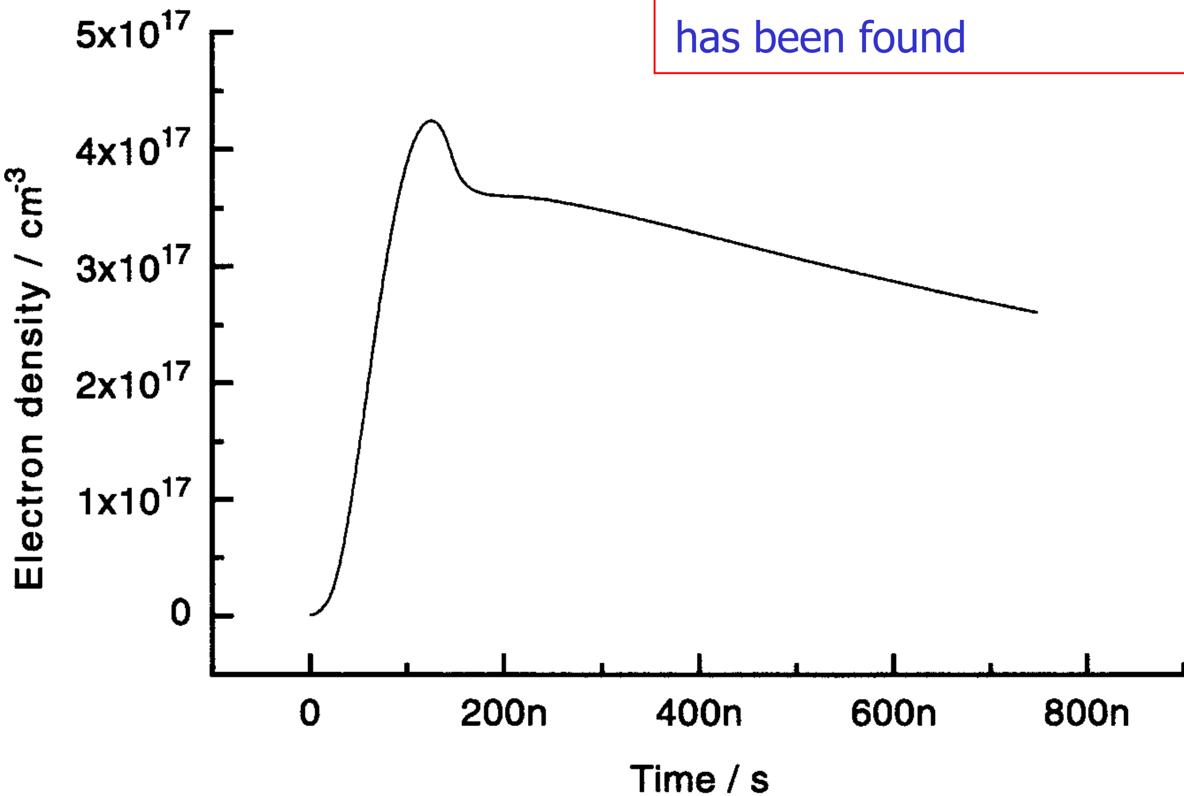
Calculations were performed using parameters derived from actual experiments on **Li_2CO_3 ablative capillary**

(*length* = 5 cm, *diameter* = 1.5 mm , *capacity* = 30 nF, *inductance* = 75 nH)

CADILAC2 code

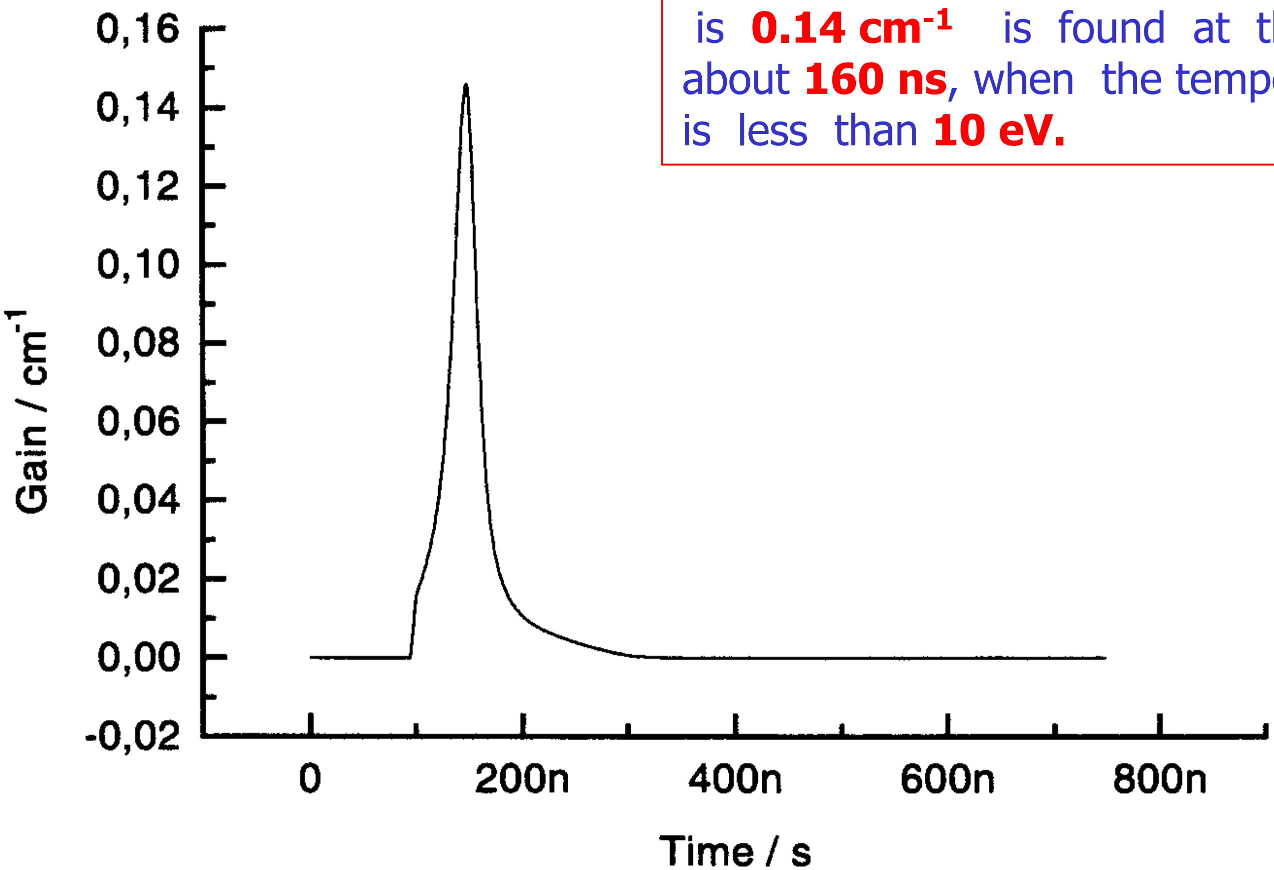
Zero-dimensional collisional-radiative model

The peak electron density at **150 ns** with a value close to **4×10^{17} cm^{-3}** has been found



CADILAC2 code

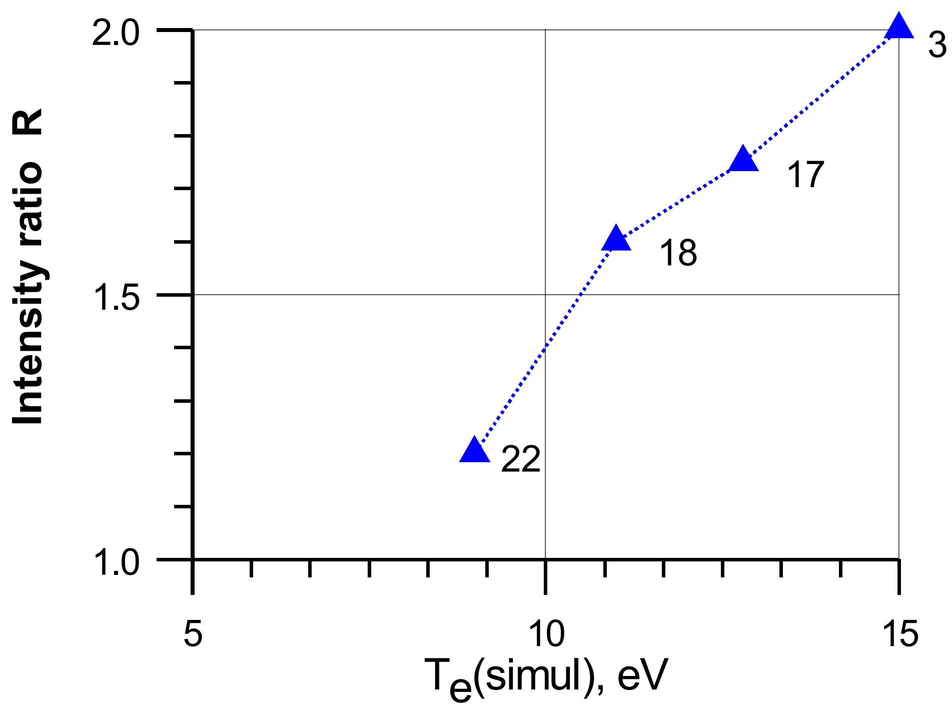
Zero-dimensional collisional-radiative model



The calculated peak value of **the gain** is **0.14 cm^{-1}** is found at the time about **160 ns**, when the temperature is less than **10 eV.**

NPINCH code

Two-temperature one-fluid **MHD** model



Correlation between simulated axial electron temperature at ***t* = 100 ns** and values of **the ratio R** of selected spectral line intensities at the same time shows that the **electron plasma temperature** on the axis is evaluated to be equal **9 ÷ 15 eV**