Using LVIC in current mode for energy spectrum reconstruction: experiments and validation

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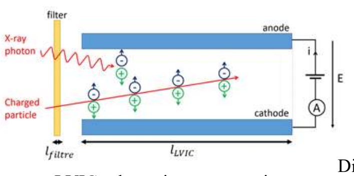
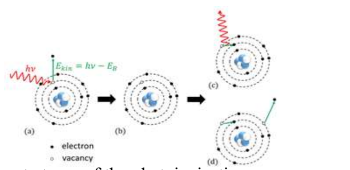
INTRODUCTION

In tokamaks with Tungsten plasma facing components such as ITER, pollution of the plasma by heavy impurities is a major concern as it can lead to radiative breakdown.
A diagnostic allowing reconstruction of the impurity distribution is thus of high interest.
The radiation emitted by such impurities is mainly composed of soft X-rays (SXR) in the [0.1, 100] keV range.
Due to the ITER radiative environment, in particular during high D-T power phase classic X-ray detectors such as semiconductor diodes might be too fragile and are thus not viable. Instead, advanced detectors (such as gas-filled detectors) are nowadays considered. The Low Voltage Ionization Chamber (LVIC) is one of the most promising candidate for X-ray measurement during the ITER nuclear phase [1]. A complete model of the detector recently developed at IRFM [2] now requires experimental validation.

LVIC SYNTHETIC DIAGNOSTIC



LVIC schematic representation



Different stages of the photoionization process: (a) absorption of the photon and ionization of the electron, (b) excited ion, (c) deexcitation through X-ray fluorescence, (d) de-excitation through Auger electron emission

For a photon flux ϕ of energy $h\nu$:

- Coefficient of transmission through the filter:

$$T(h\nu) = \exp(-N_m * \sigma_{tot}(h\nu) * l_{filter})$$

- Coefficient of photoelectric absorption in the gas:

$$A(h\nu) = 1 - \exp\big(-N_g * \sigma_{ph}(h\nu) * l_{LVIC}\big)$$

- X-ray fluorescence (if $h\nu > E_X$): Charge lost: $\Delta C_f = \frac{E_B}{W}$

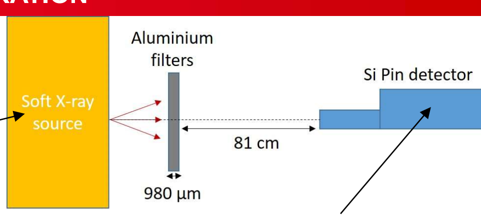
For Argon, probability $P_f = 14\%$, $E_X = 3.2\ keV$, $E_B = 2.9\ keV$, $W = 26\ eV$ [3]

- Statistical fluctuations on the primary electron cloud N:

$$\frac{\sigma_N^2}{<N>^2} = \frac{F}{<N>}$$, F = Fano noise (0.23 for Argon) [4]

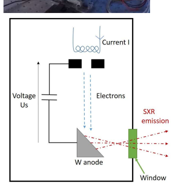
A matrix computation is used

SOURCE CALIBRATION

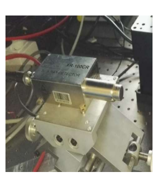


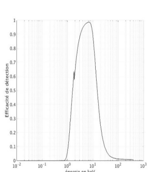
SRI SB-50-1k

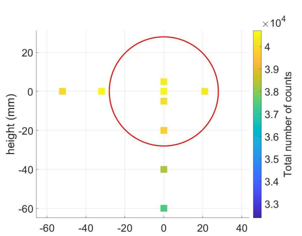
XR-100CR



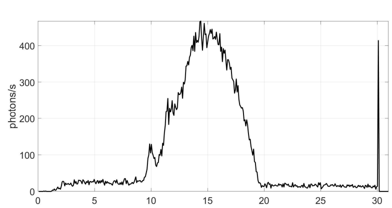
Source spatial distribution







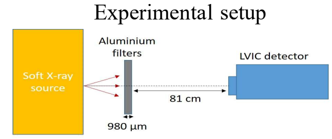
- Uniform spectrum on LVIC
- Good statistics in terms of counts
- W lines visible at 9,96keV and 11,42 keV



Acquired spectrum (over 15s)

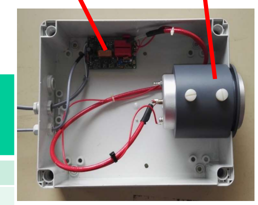
EXPERIMENTAL RESULTS – MODEL VALIDATION

Experimental setup



Al filter width (µm)	Measured Voltage (mV)	Simulated Voltage (mV)	Relative error (%)
980	7.36	7.71	4.5
0	191.22	203.29	5.9

Amplifier LVIC



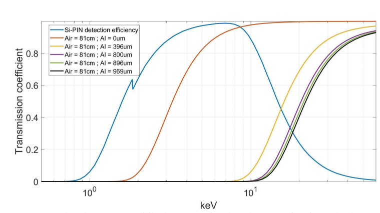
SPECTRUM MODELING

Modeling of the spectrum using a simple mathematical function:

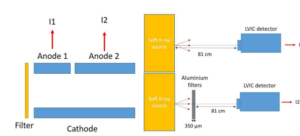
$$f(X) = \begin{cases} 0, & h\nu < 10\,keV \\ X_1 * \exp\left(-\frac{(h\nu - 9.961)^2}{0.03}\right) + X_2 * \exp\left(-\frac{(h\nu - 11.42)^2}{0.15}\right) + X_3 - X_4 * h\nu, & 10keV < h\nu < h\nu_{lim} \\ X_5, & h\nu_{lim} < h\nu < 30.11keV \\ 0, & h\nu > 30.11keV \end{cases}$$

SPECTRUM RECONSTRUCTION

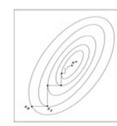
Measuring currents with different filters allows the minimization of r(X) to reconstruct the incoming spectrum: $\phi = f(X)$



Transmission coefficient of Si-Pin and aluminium widths

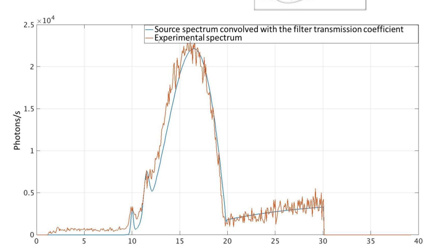


Example of the applied method for a 2 chambers mimicking



Chi-square minimisation $r(X) = \| I_{meas} - I(f(X)) \|_2^2$

- Coherent spectrum reconstruction
- Bremsstrahlung nicely reproduced
- Discrete sets of current measurements associated to chi square minimisation are enough to get spectral information



CONCLUSION

- LVIC synthetic modelling [2] has now been experimentally validated.
- The inversion method developed in [5] has been successfully applied to experimental measurements demonstrating the capability of a multi-chamber LVIC to reconstruct spectral information from a discrete set of measured current.
- Next step is to construct a multi-chamber LVIC and perform experimental testing on tokamaks.

References

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