

THEORETICAL AND NUMERICAL MODELLING OF OPTICAL FIBRE PREFORM DOPING

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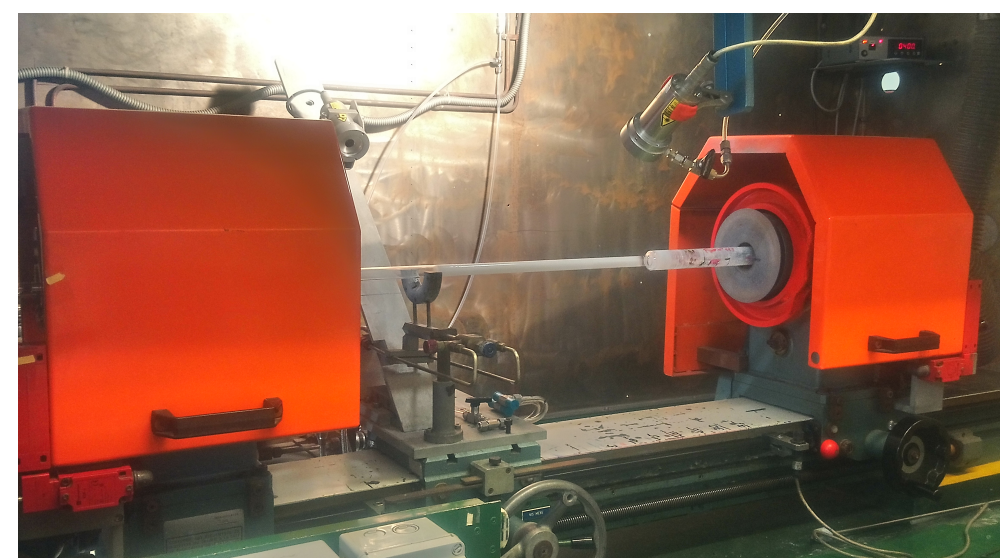
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Abstract

Incorporation of specific ions inside the core of optical fibres is a well-known process used to modify their properties. A new experimental doping protocol has been developed, based on a gradual soaking of the fibre preform [1]. We built a flexible model able to realise simulations of preform doping with an aqueous solution of aluminium ions (Al^{3+}) that involves only two simple phenomena: diffusion and adsorption-desorption [2]. It produces preliminary but promising results when they are compared to experimental doping.

1. MCVD process and solution doping



Preform fabrication

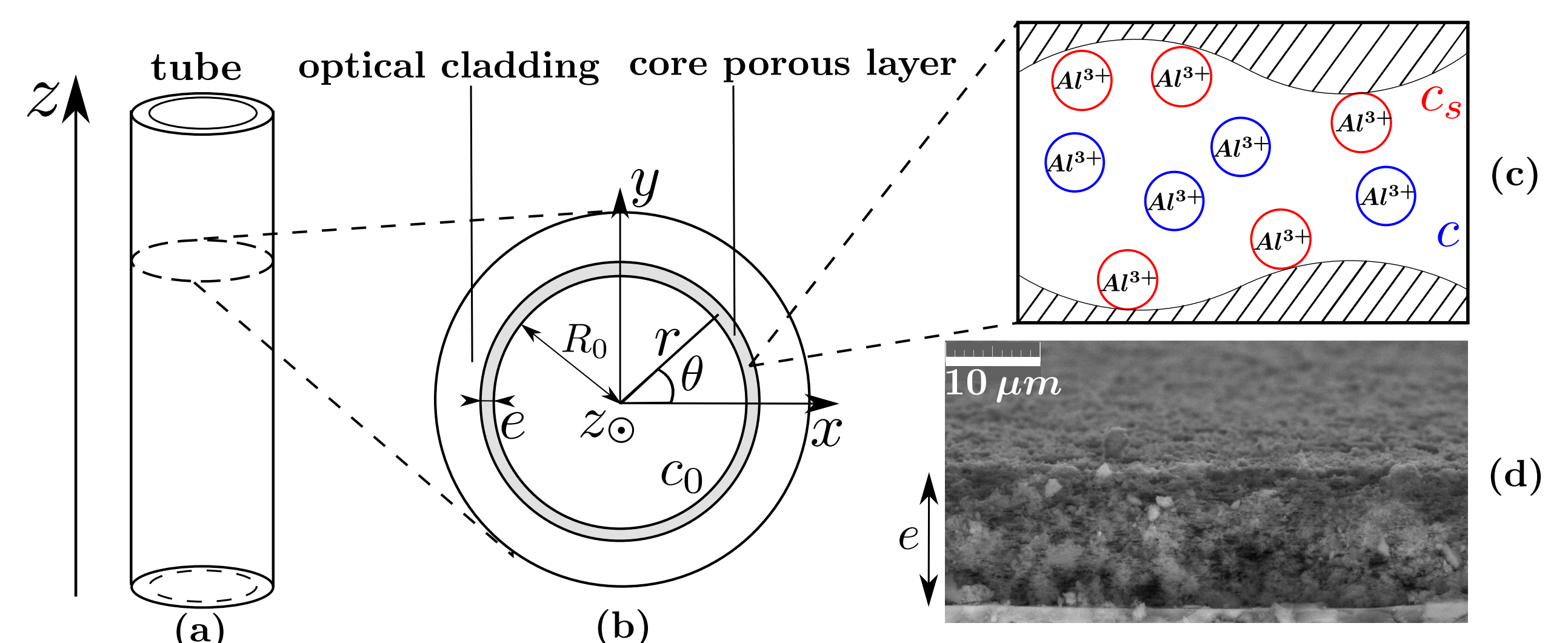
- Silica tube heated ($\sim 1500^\circ C$)
- Deposit of SiO_2 soot on the inner surface of the tube
- Collapse to form the preform rod ($\sim 2000^\circ C$)



Solution doping technique

- Soaking of the core porous layer with the solution containing the wanted ions, after the layer deposit step
- New doping protocols were set

2. A simple model based on two phenomena



(a) Silica tube containing the core porous layer, (b) tube transverse section (c) sketch of the porous layer, (d) scanning electron image (SEM) of a porous layer.

Simplifying assumptions

- Homogeneous core porous layer
- Doping solution as an infinite reservoir of ions
- Undoped cladding layer
- Lag between ions and solvent diffusion

The doping model distinguishes 2 kinds of ions: the "free" ones in the pores (concentration c in M) and the "adsorbed" ones on the porous surface (concentration c_s in M) with a maximum capacity $c_{s,max}$. The temporal (t) evolution of these quantities rely on the following equations:

Diffusion

$$\frac{\partial c}{\partial t} \Big|_{diff.} = D_{eff} \left(\frac{\partial^2 c}{\partial r^2} + \frac{1}{r} \frac{\partial c}{\partial r} \right) \quad (1)$$

- Only radial diffusion
- Effective diffusion coefficient D_{eff} taking porous structure into consideration
- **Non-analytical solution for the chosen boundary conditions**

Adsorption-desorption

$$\frac{\partial c_s}{\partial t} = k_a c (c_{s,max} - c_s) - k_d c_s \quad (2)$$

- Langmuir kinetic model
- 2 terms related to the adsorption rate (k_a) and the desorption rate (k_d)
- **Analytical solution by partial fraction decomposition**

3. An algorithm to deal with non-analytical solution

Which numerical scheme and why?

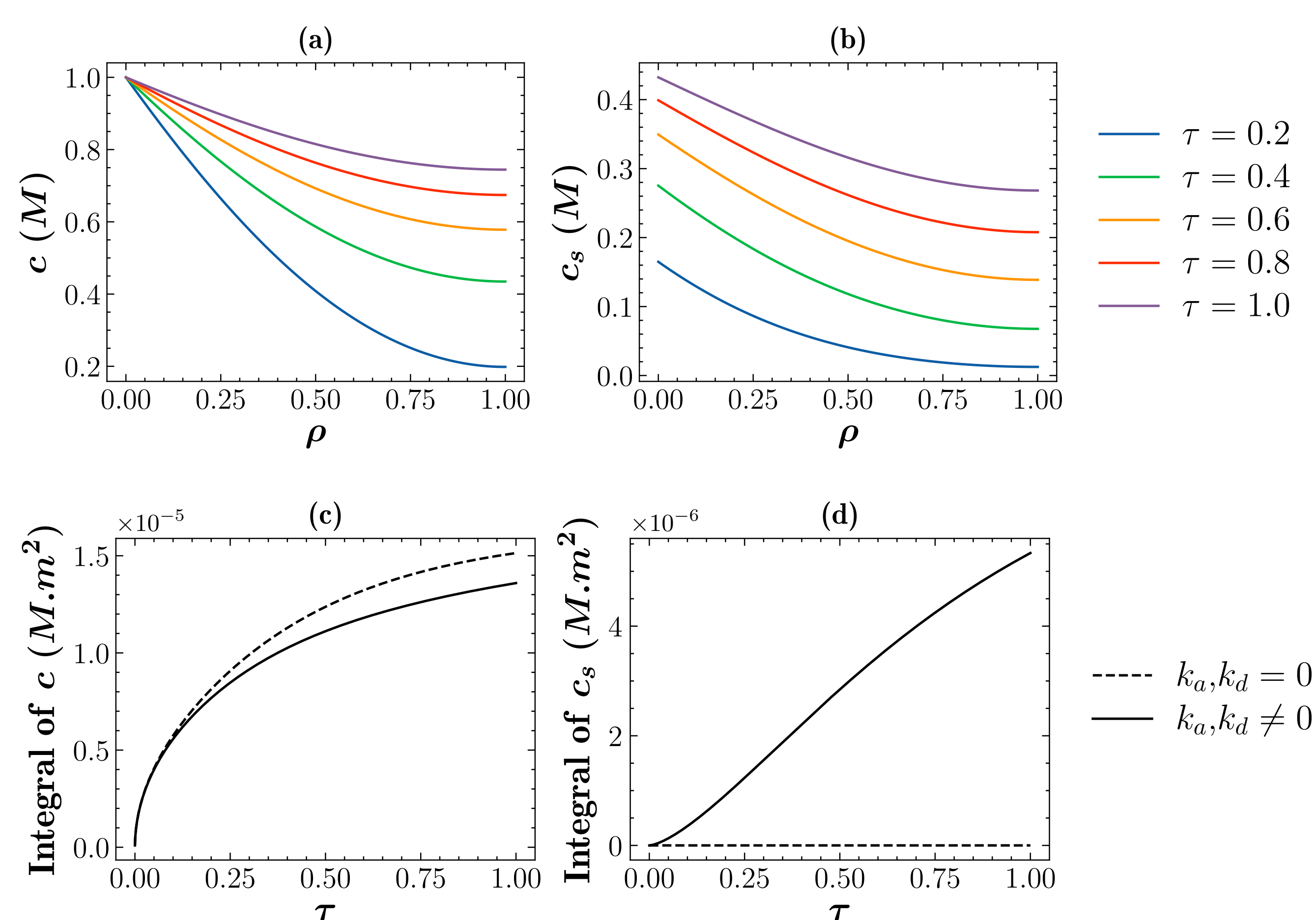
In order to solve both diffusion and adsorption-desorption, we used a **semi-implicit finite differences scheme (FDS)** which presents several benefits:

- Unconditionally stable
- Sturdy to time increments modifications
- Better convergence to analytical solution in a 1D diffusion

How does the algorithm work?

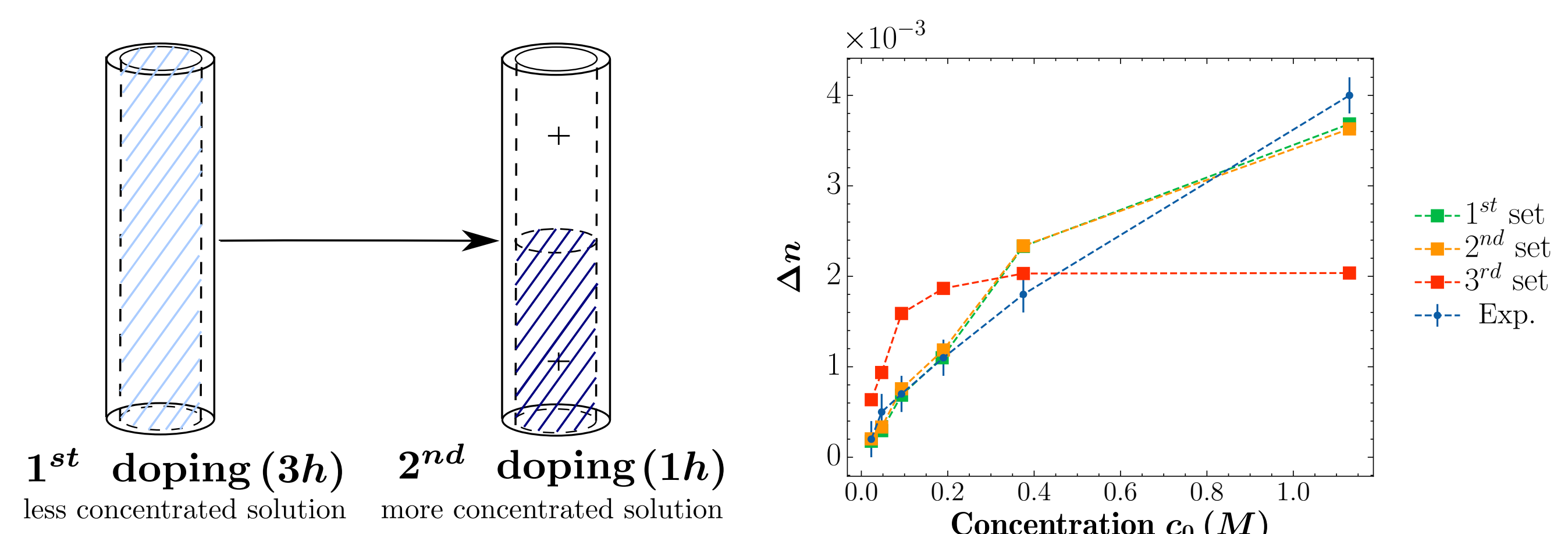
The code takes the doping protocol as an input and provides in the output the concentrations' profiles with respect to the normalised radius ρ and their integrals for different normalised times τ . The algorithm works with the following steps:

- **1.** Ions diffusion: The numerical solution for (1) is found with the FDS,
- **2.** Ions adsorption: c_s is computed with the analytical solution of (2),
- **3.** c is modify to ensure that matter is conserved,
- **4.** The previous steps are repeated until doping time is up.



Concentrations profiles of c (a) and c_s (b) for different τ and their integrals (c (c) and c_s (d)) with respect to τ for $e = 100 \mu m$, $R_0 = 8.5 mm$, $k'_a = 1 M^{-1}$ and $k_d/k_a = c_{s,max} = 1 M$.

4. An early comparison with a real doping protocol



Parameters	D_{eff} ($\times 10^{-11} m^2.s^{-1}$)	e (μm)	R_0 (mm)	T_0 (s)	k'_a (M^{-1})	k_d/k_a (mM)	$c_{s,max}$ (M)
1 st set	5	14	8.5	3.95	0.2930	0.1685	10
2 nd set	5	50	8.5	50	3.71	0.1685	10
3 rd set	5	50	8.5	50	10	0.1685	0.01

(left picture) Sketch of experimental doping protocol. The crosses represent considered points for Δn measurements. (right picture) Δn with respect to concentration c_0 for the numerical (table) and experimental data.

- 3 preforms were doped with a specific protocol shown in the figure above. Numerical simulations with the same protocol were lead with 3 sets of different parameters in order to realise a first comparison.
- Some parameters appear due to normalisation such as the characteristic time of diffusion T_0 and $k'_a = k_a T_0$.
- The comparison with the numerical results witnesses a global agreement with the experimental trend. The last set shows a case where saturation appears.

Further improvements of the model

The model relies on adsorption-desorption parameters that yet remain uncertain. Some assumptions such as the way ions diffuse after the solvent could be different. As far as the numerical work is concerned, adding the diffusion along the z axis of the tube would allow to plot index differences with respect to the position along the preform.