

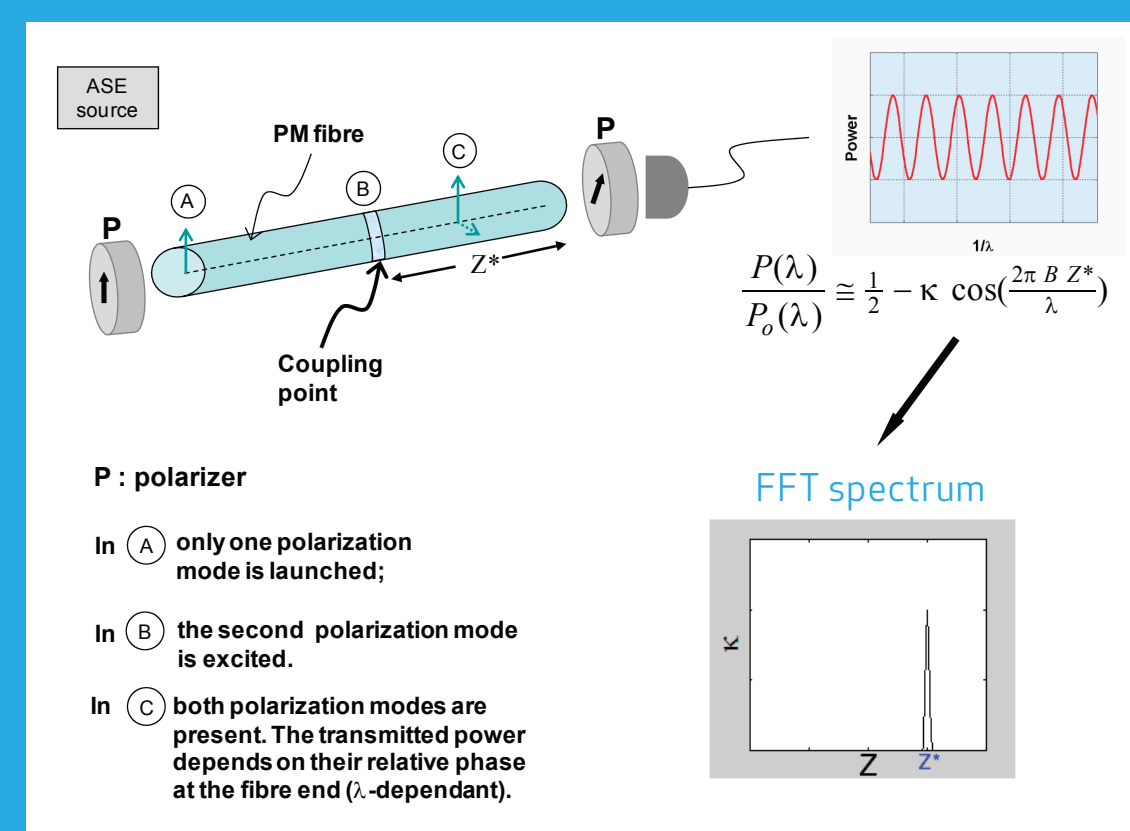
MODELING OF POLARIZATION MODE COUPLING INVOLVED IN A CAPILLARY OPTICAL FIBER SENSOR

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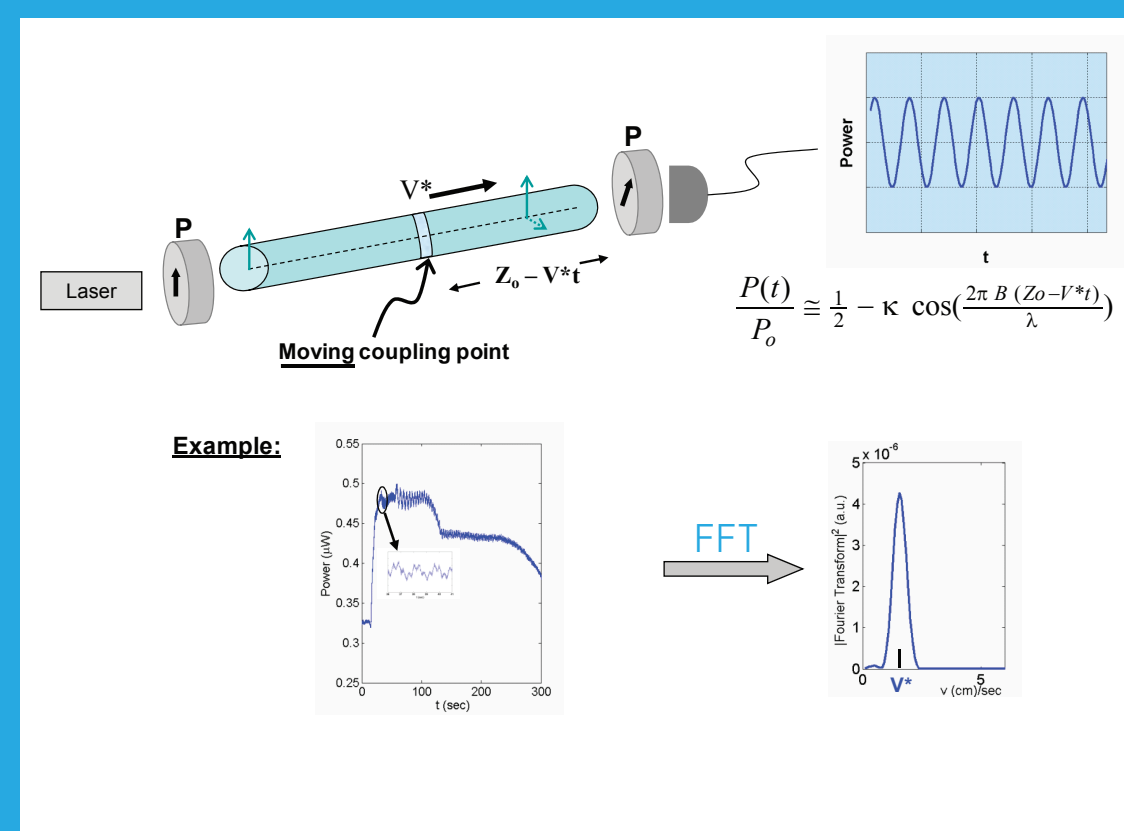
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INTRODUCTION

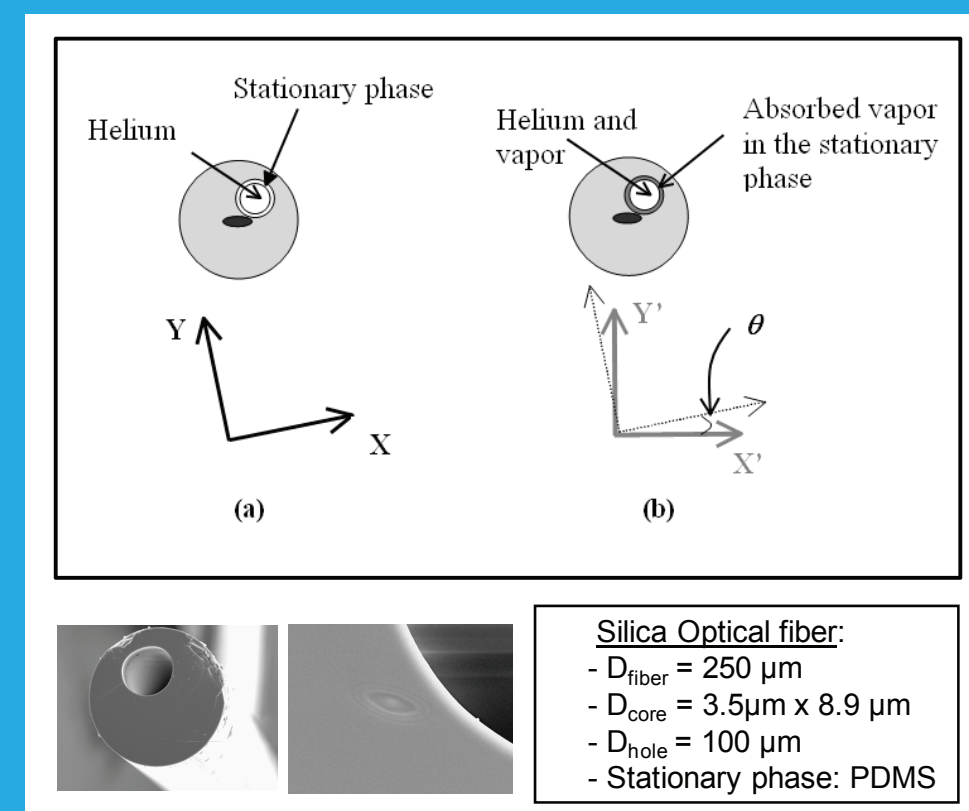
Polarization interferometry with **static** coupling points



Polarization interferometry with **moving** coupling points



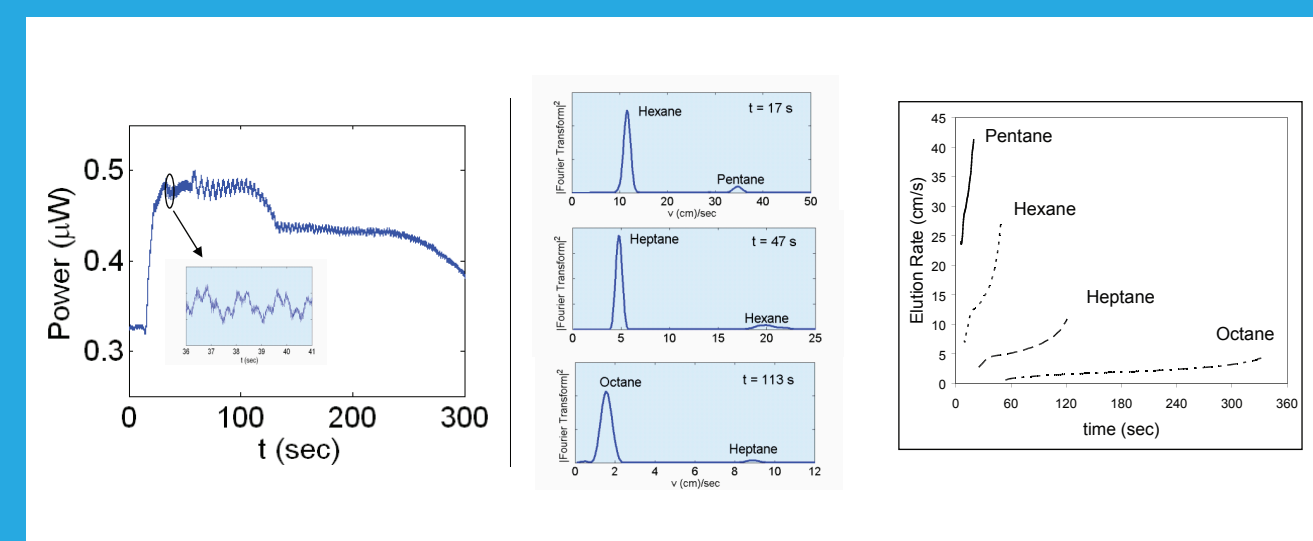
INO CUSTOM CAPILLARY PM FIBER FOR GAS CHROMATOGRAPHY



- **Principle of gas chromatography:** different vapors propagate at different velocities down the capillary. Velocity is then a signature!
- A custom capillary PM fiber can then serve to a new type of gas chromatography based on polarization interferometry.

VAPOR IDENTIFICATION

Example: mixture of Heptane, Pentane, Hexane and Octane



- Windowed Fourier Transforms allow real-time detection of the gas constituents.
- The different vapors are identified well before they exit the capillary, in contrast with standard gas chromatography. This can represent a significant advantage.

MODELING OF A NON-UNIFORM (DISTRIBUTED) MOVING COUPLING ZONE

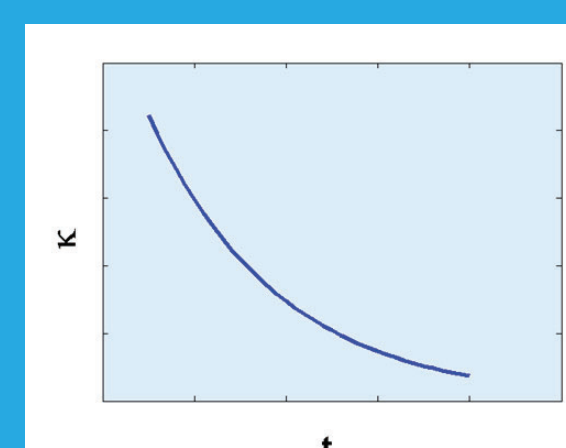
The coupling between the two polarization components is locally dependent on the gas concentration $C(z, t)$. The distributed coupling can be viewed as a cascade of birefringent plates of infinitesimal thickness δz and orientation $\theta(z)$. The passage through each plate can be analyzed in terms of Jones matrices.

(differential version of the Jones matrix formalism)

$$\frac{d}{dz} \begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} \beta_x(z) & -\frac{d\theta(z)}{dz} \\ \frac{d\theta(z)}{dz} & \beta_y(z) \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix} \quad \frac{d\theta}{dz} = \frac{\partial \theta}{\partial n} \frac{dn}{dz} = \frac{\partial \theta}{\partial n} \frac{dn}{dC} \frac{dC}{dz} = \kappa \left(\frac{dC}{dz} \right)$$

Weak coupling limit =

$$\kappa = K \left| \int_0^L \left(\frac{dC}{dz} \right) \exp\left\{ i \frac{2\pi B}{\lambda} z \right\} dz \right| \quad (1)$$



The coupling strength is locally dependent on the **gradient** of the vapor zone distribution. The beat length represents the scaling length. To cause a significant coupling, the variation of gas concentration must be non adiabatic. As the gas diffuses, the gradient dC/dz decreases and so does κ .

GAS DIFFUSION AND AMPLITUDE DECAY

$$\frac{\partial C(z, t)}{\partial t} + v \frac{\partial C(z, t)}{\partial z} = D_{eff} \frac{\partial^2 C(z, t)}{\partial z^2} \quad D_{eff}: \text{effective diffusion coefficient}$$

v : vapor zone velocity (migration rate)

General solution: $C(z, t) = \frac{1}{\sqrt{4\pi D_{eff} t}} \int_{-\infty}^{+\infty} C_o(z') \exp\left[-\frac{(z - vt - z')^2}{4 D_{eff} t} \right] dz' \quad (2)$

(1),(2) = $\kappa = \kappa_o \exp\left(-\frac{4\pi^2 B^2}{\lambda^2} D_{eff} t\right) \quad \kappa_o = K \frac{2\pi B}{\lambda} \left| \int_{-\infty}^{+\infty} C_o(z) \exp\left[-i \frac{2\pi B}{\lambda} z\right] dz \right|$

- Whatever the initial vapor zone distribution $C_o(z)$, the signal amplitude decay is exponential.
- If the initial distribution (at the entrance into the capillary) extends over a length a few times shorter than the beat length ($L_b = 2\pi B/\lambda$), then:

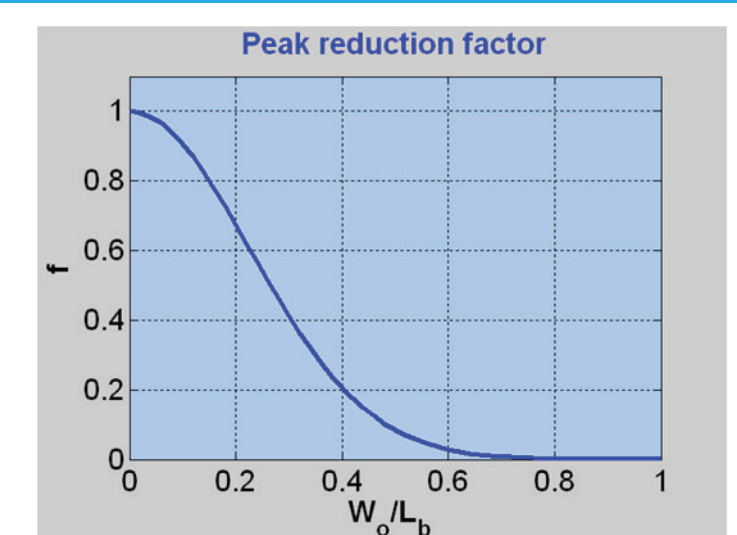
$$\kappa_o \cong K \frac{2\pi B}{\lambda} \int_{-\infty}^{+\infty} C_o(z) dz = K \frac{2\pi B}{\lambda} N$$

- In that case, the maximum amplitude is directly related to the total amount of analyte in the capillary and is independent of the exact distribution $C_o(z)$, which greatly simplifies the data treatment.
- Otherwise, a good control of the initial distribution is required for a reliable calibration.

Example: Gaussian distribution

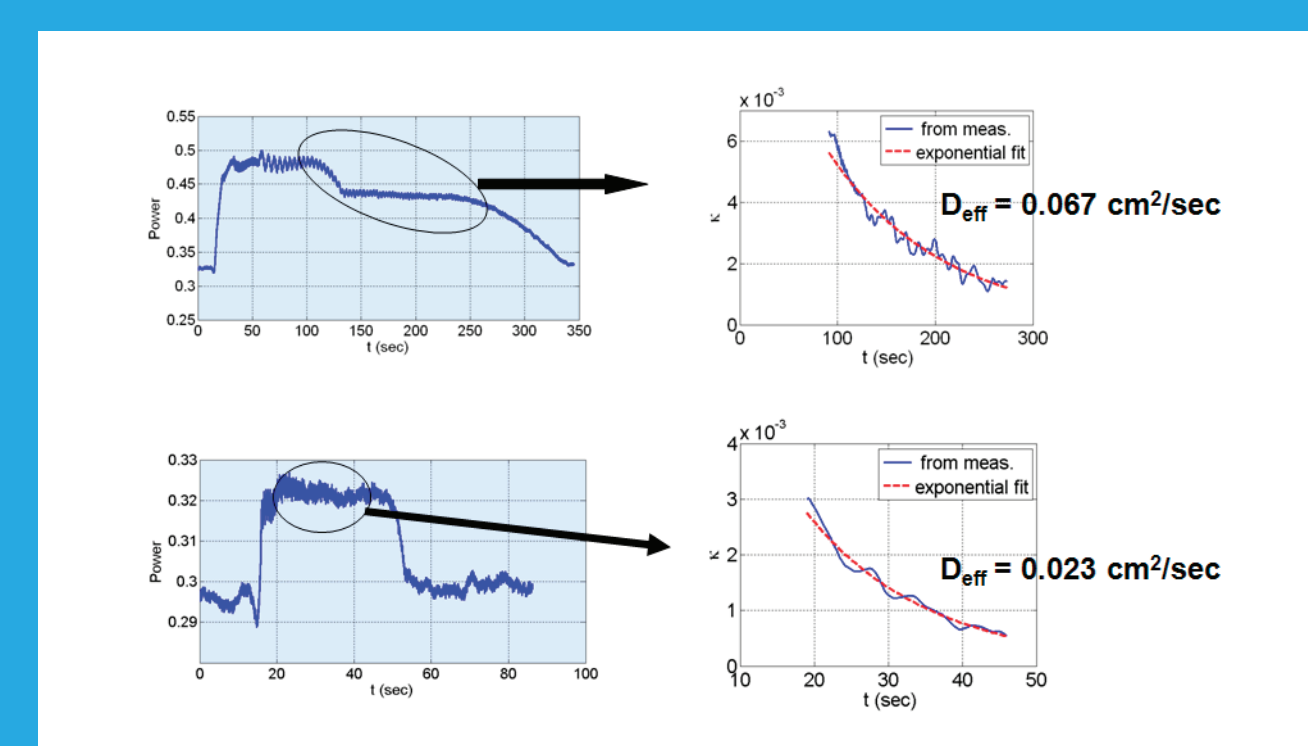
$$C_o(z) = C_o \exp\left(-\frac{z^2}{W_o^2}\right) = \frac{N}{\sqrt{\pi} W_o} \exp\left(-\frac{z^2}{W_o^2}\right)$$

$$\Rightarrow \kappa_o = K \frac{2\pi B}{\lambda} N \exp\left(-\pi^2 \frac{W_o^2}{L_b^2}\right) \cong f K \frac{2\pi B}{\lambda} N$$



- The maximum coupling strength decreases significantly when the initial distribution extends over a width comparable to or longer than the beat length.

EXPERIMENTAL TESTS



CONCLUSION

- The custom PM capillary fiber allows a quick identification of the analytes.
- Modeling predicts an exponential temporal decay of the signal amplitude caused by the gas diffusion in the capillary.
- Experiments confirm this, but further work has to be done for a more accurate description and hence a reliable quantification.
- Conditions are established for a direct relation between the maximum signal amplitude and the concentration of the analyte.