Chaire d´excellence en recherche du Canada sur

l´innovation en photonique dans le domaine de l´information et des communications

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Zero Dispersion Modeling in As2S3-Based Microstructured Fibers

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Introduction

An important step in designing a microstructured optical fiber is the computation and management of its dispersion curve. It is well known that material bulk dispersion can be modeled analytically using the Sellmeier equation for the refractive index. However, when it comes to modal propagation confined in an optical waveguide of complex geometry, one has to rely on numerical methods. The purpose of our work was to determine which geometrical parameters influence the total dispersion (also called chromatic dispersion).

Computational methods

It is easy to show that Maxwell's equations for linear, non-magnetic and non-conductive material imply this equation for the electric field (with time-harmonic dependence) :

$$\nabla \times \nabla \times \vec{E} = \tfrac{4\pi^2}{\lambda^2} n(\lambda)^2 \vec{E}$$

where λ is the free-space wavelength, and n is the refractive index. Using the mode analysis study in Comsol, we computed solutions of this form:

$$\vec{E}(x,y,z,t) = \mathrm{Re}\left(\vec{E}_c(x,y) e^{i\left(-t\frac{2\pi c}{\lambda} + \beta z\right)} \right)$$

where $\vec{E}_c$ is a three-dimensional complex-valued field. For a given range of free-space wavelengths λ, we had to find the corresponding eigenvalues (also called propagation constants) $\beta(\omega) = \beta(2\pi c/\lambda)$ related to guided modes. Propagation constant and chromatic dispersion D are related by this equation

$$D(\lambda) = \frac{-2\pi c}{\lambda^2}\frac{d^2\beta}{d\omega^2} = \frac{-\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2}$$

where :

$$n_{eff}(\lambda) := \frac{\beta\left(\frac{2\pi c}{\lambda}\right)}{k_0} = \frac{\beta\left(\frac{2\pi c}{\lambda}\right)}{2\pi/\lambda}.$$

is the effective refractive index associated with λ. In order to approximate this second derivative, we used this difference formula

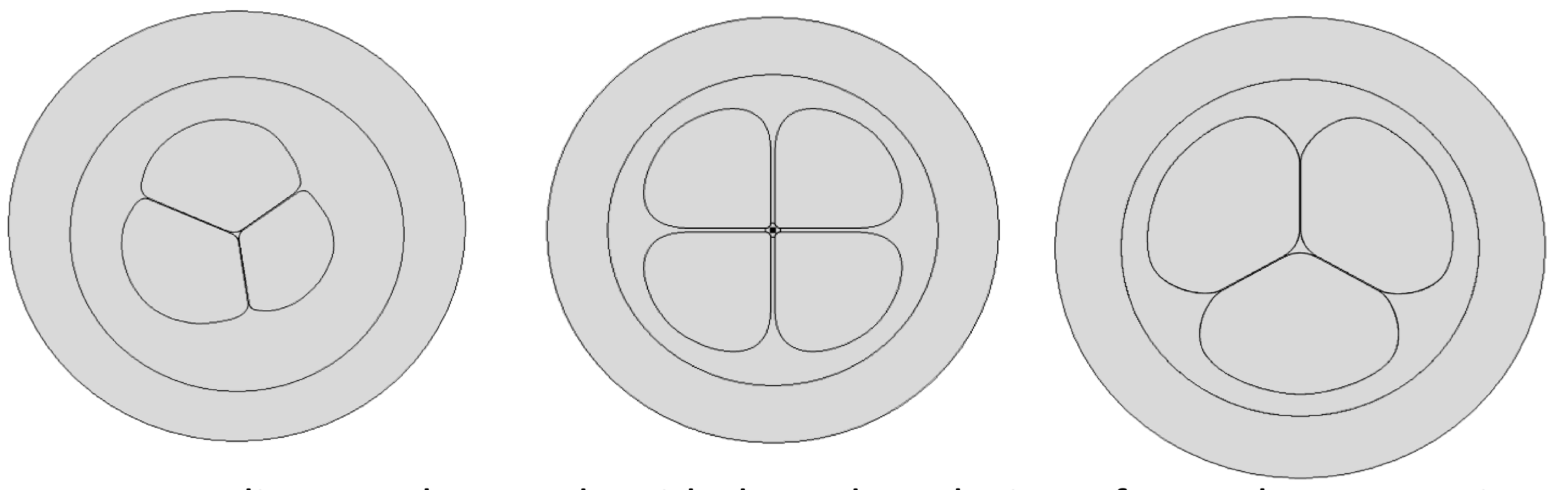
$$\frac{d^2 n_{eff}}{d\lambda^2}(\lambda) \approx \frac{-2n_{eff}(\lambda_{-2}) + 32n_{eff}(\lambda_{-2}) - 60n_{eff}(\lambda_0) + 32n_{eff}(\lambda_1) - 2n_{eff}(\lambda_2)}{24 \cdot \Delta\lambda}$$

where : $\lambda_k := \lambda + \Delta\lambda \cdot k$

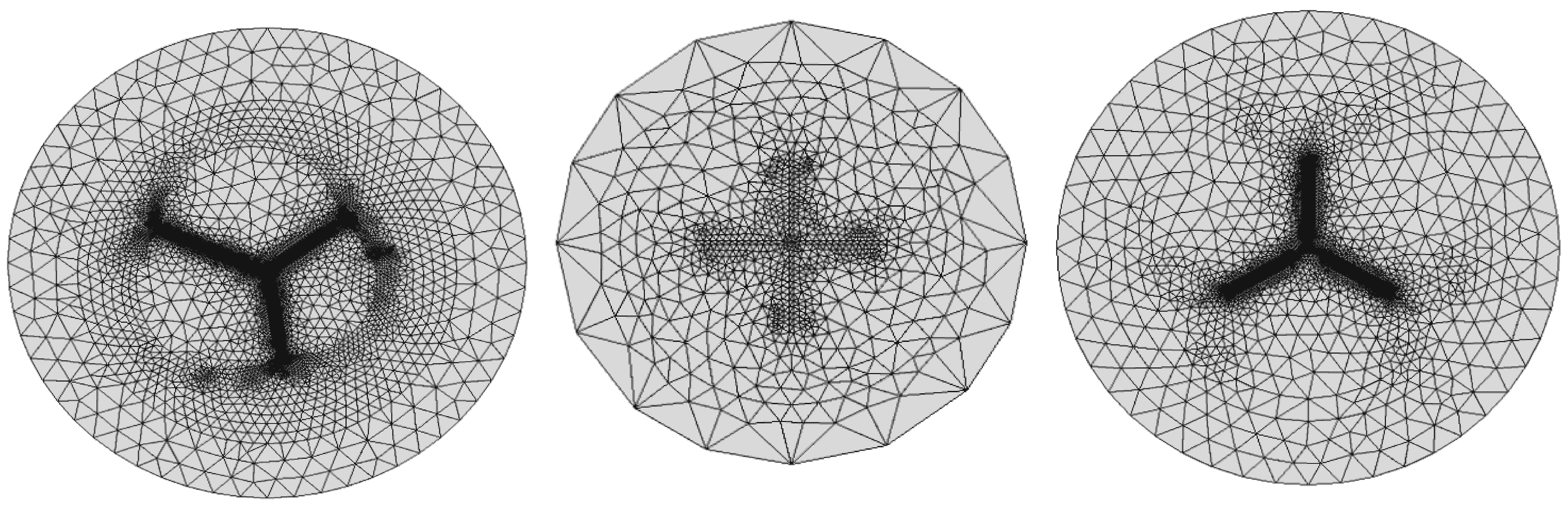
Because we modeled propagation of light in microstructured fibers, we had to use a perfectly matched layer. That substantially complicated our search for guided modes.

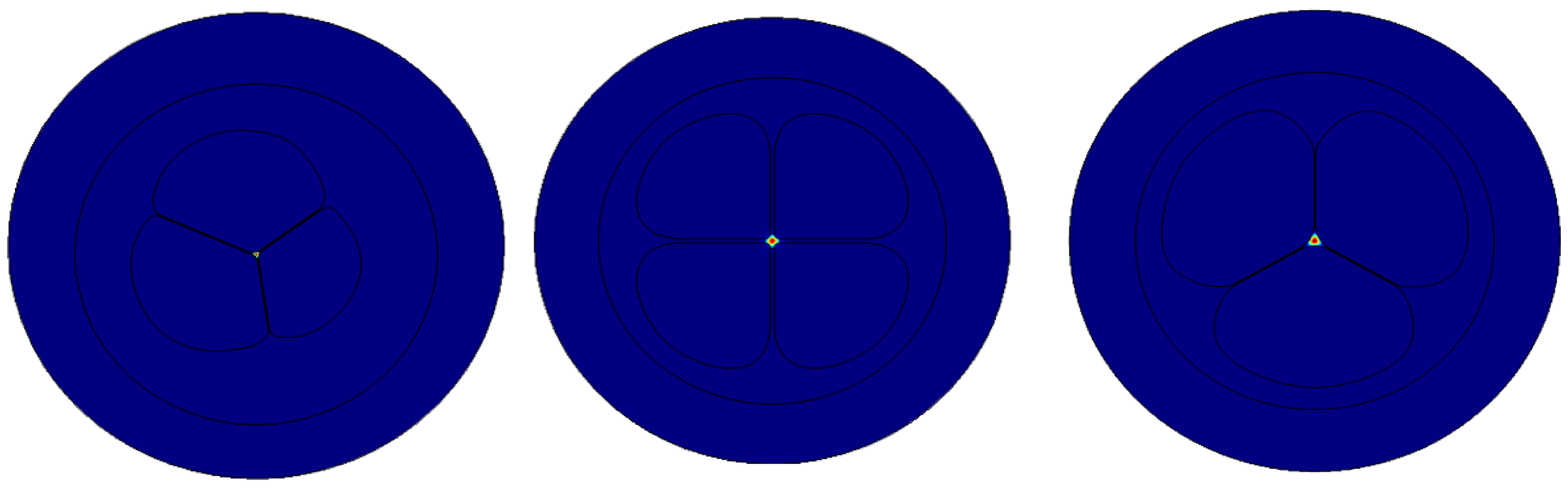
Geometries and meshes

We used both empirical and parameterized geometries in our simulations.



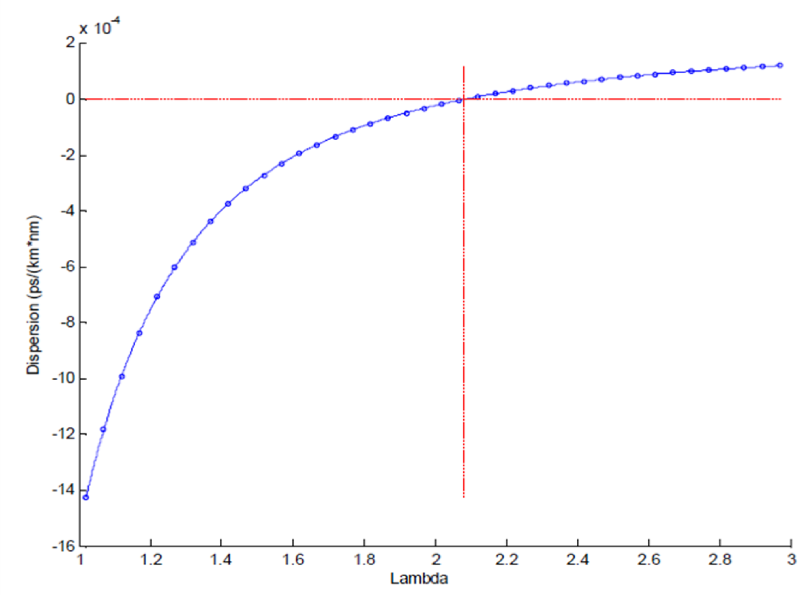
The corresponding meshes and guided mode solutions for such geometries are given below.

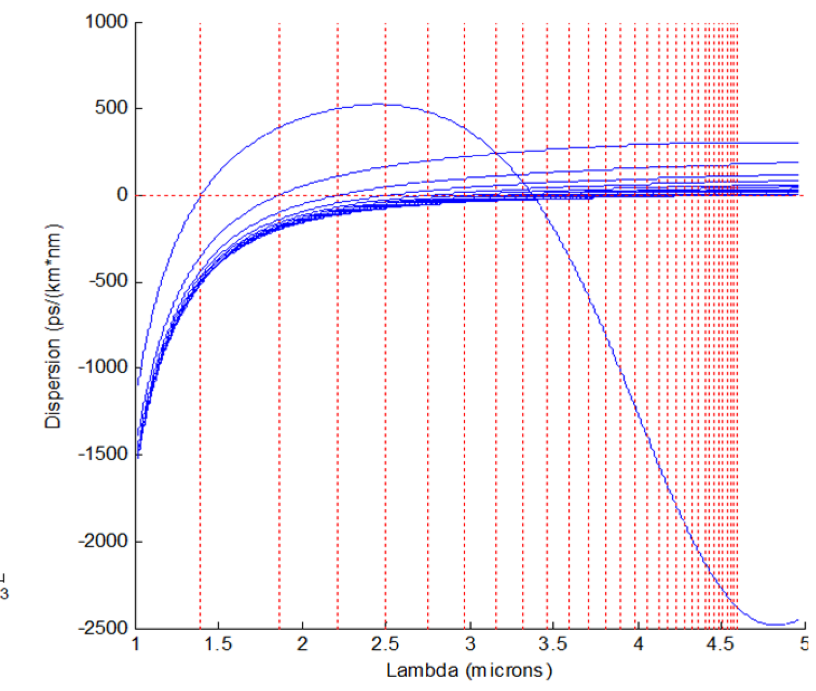


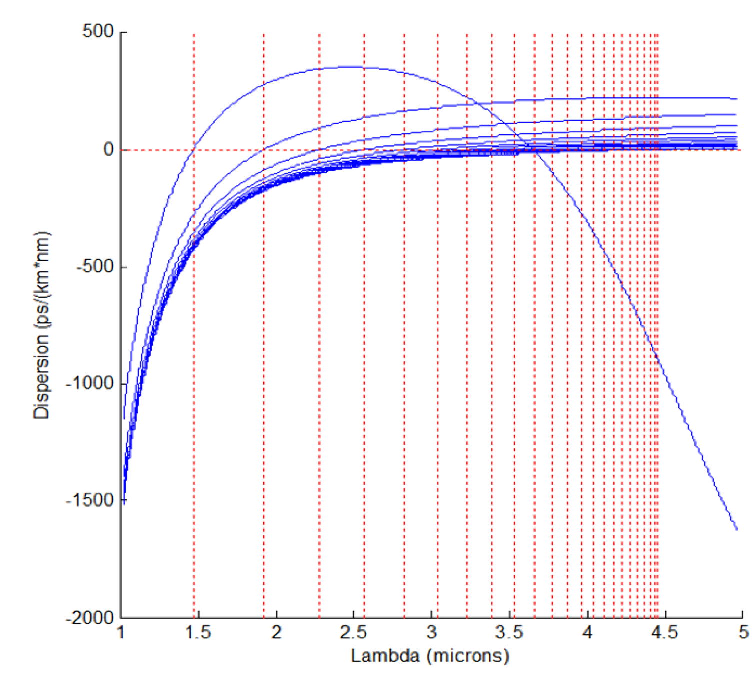


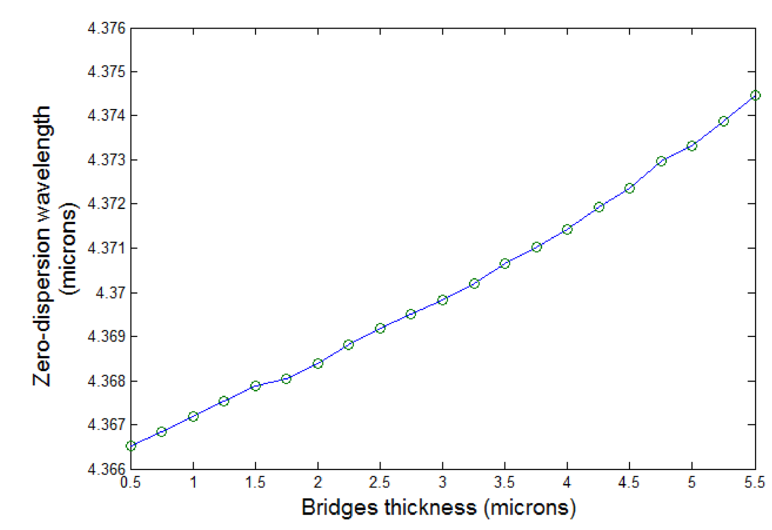
Results

We obtained the following dispersion curves for the three geometries illustrated above. In the 1st and 3rd plots, we computed dispersion curves for core diameters ranging from 1 to 25 and from 1 to 30 microns.









Conclusion

Our simulations demonstrate that the core diameter is the main parameter affecting the chromatic dispersion, while the bridges thickness only had a slight impact.

In future works we are interested in integrating the nonlinear optical effects and the stochastic contributions from trace impurities, into our numerical model, in order to predict nonlinear effects that are likely to be generated by a given laser pumping.

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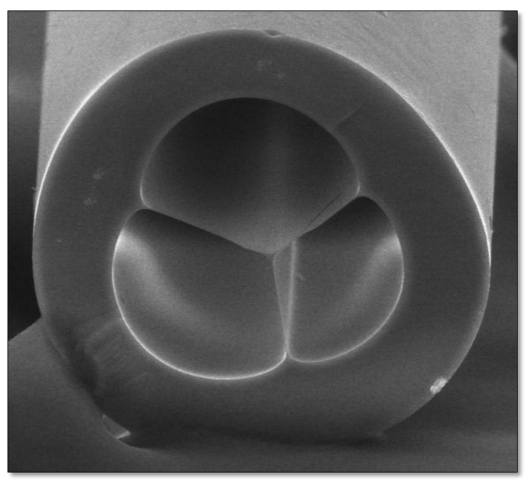

Cross-section of a microstructured optical fiber