Simulating Chemical Etching of Optical Fiber to create NSOM Probe using COMSOL Multiphysics®

M. N. Hussain[1], X. S. Udad[1], E.C. Edwards[1], J. C. Woehl[1]

1. University of Wisconsin – Milwaukee, Milwaukee, WI, USA

Introduction

Chemically etching optical fiber with HF forms cone shaped Near-field scanning optical microscopy (NSOM) probe and the cone angle of probe is dependent on etching time.

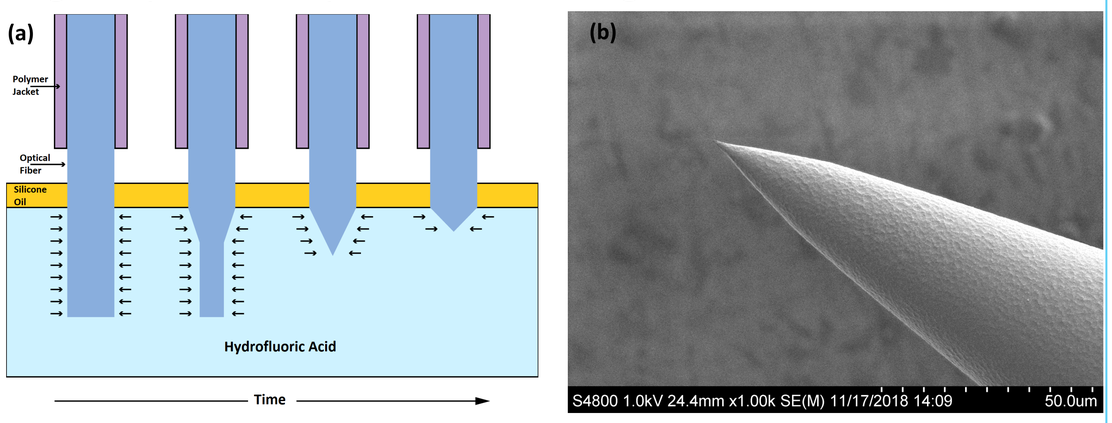

Figure 1. (a) Schematic of chemical etching process of optical fiber, (b) SEM image of NSOM probe.

Numerical Model

Model simulates etching of SiO_2 at the interface of optical fiber-HF solution.

2D diffusion model was simulated using Transport of Diluted Species (tds) and Laminar Flow (spf) interfaces.

Movement of etch front was implemented using Deformed Geometry (dg) interface.

Geometry of the model consists of the following:

- 40% HF solution
- Optical Fiber outer surface (2 mm above the solution)
- predefined etch form of thickness 5 µm for enhanced mesh movement

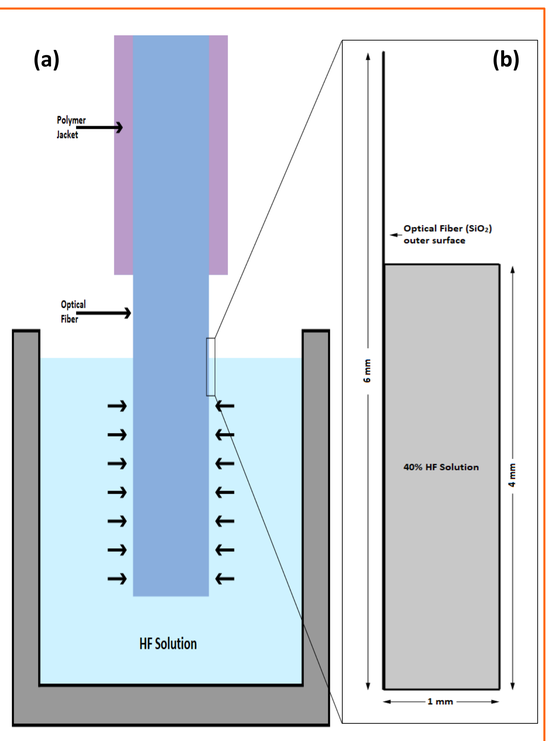

Figure 2. (a) Schematic of Optical fiber in HF solution, (b) 2D COMSOL model geometry.

Governing Equations

Convection-Diffusion Equations:
(Transport of Diluted Species)

$$\frac{\partial c_i}{\partial t} + \nabla \cdot \mathbf{J}_i + \mathbf{u} \cdot \nabla c_i = R_i$$
$$\mathbf{J}_i = -D_i \nabla c_i$$

Navier-Stokes equations:
(Laminar Flow)

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot [-p\mathbf{I} + \mathbf{K}] + \mathbf{F}$$
$$\rho \nabla \cdot (\mathbf{u}) = 0$$
$$\mathbf{K} = \mu\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right)$$

Diffusion Model

Etching Reaction: $SiO_2 + 6HF \longrightarrow H_2SiF_6 + 2H_2O$

Etch front movement (1st order reaction):

$R = k \cdot c$ $\qquad$ $v_n = R \cdot K_D$ $\qquad$ $K_D = \frac{M_{Si}}{m \cdot \rho_{Si}}$

where R – reaction rate at the interface HF solution-optical fiber

k – reaction rate constant, c – HF solution concentration,

m – quantity of F atoms consumed for dissolution of one Si atom.

Results

Simulation result in Fig. 3 shows the deformation shape of the optical fiber outer surface depends on solution flow velocity. Results in Fig. 4 show that with increasing time the deformation depth and curvature of this outer surface increases.

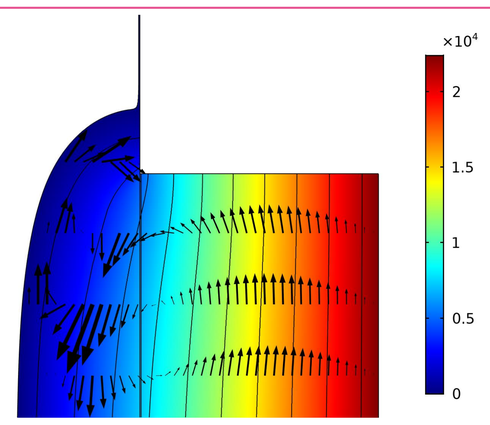

Figure 3. Solution flow velocity.

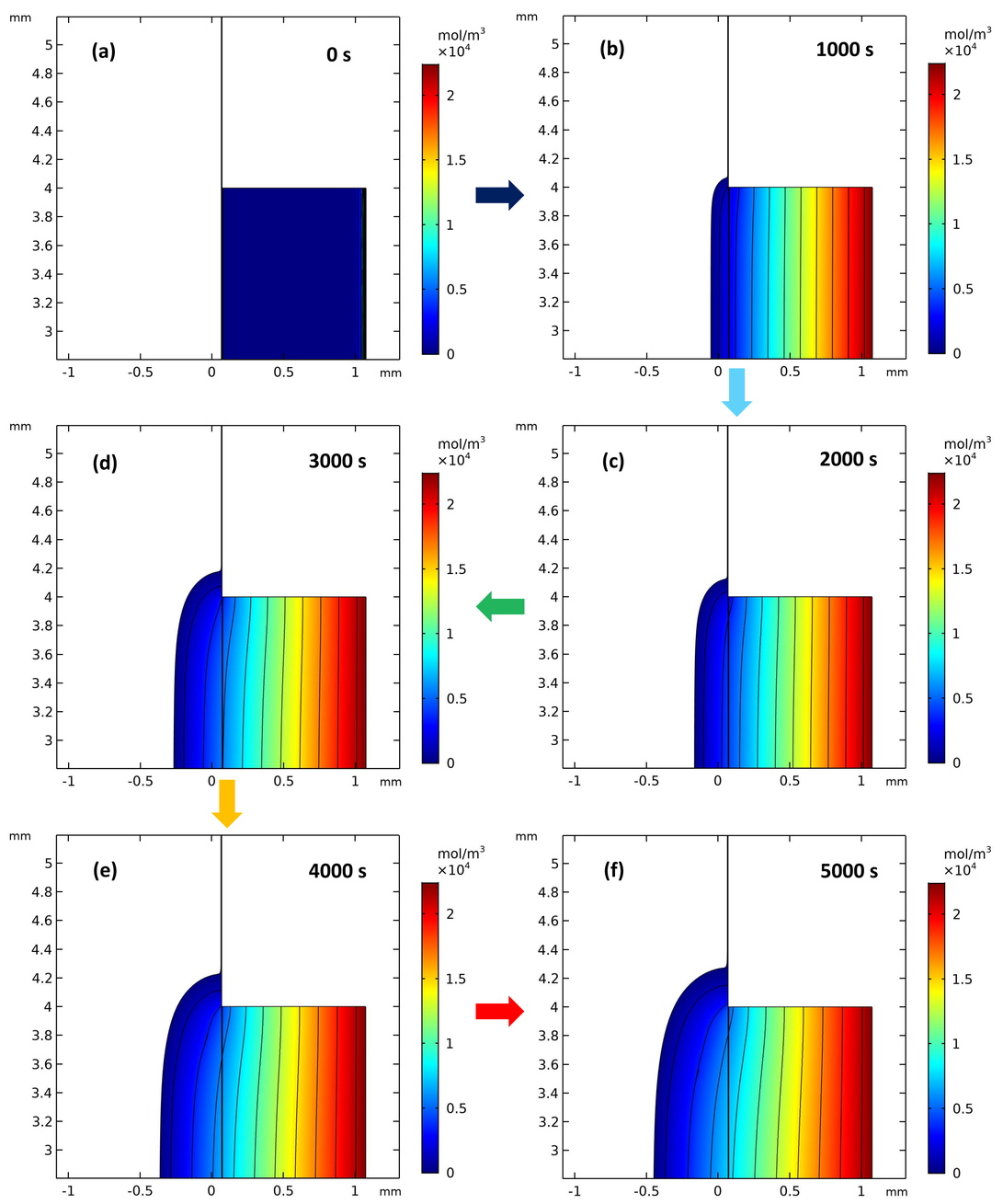

Figure 4. (a-f) Simulated deformation of optical fiber outer surface over time.

Conclusions

The deformed geometry from the simulated results suggest that the etching of optical fiber creates a cone shaped NSOM probe and the cone angle of the probe will become wider with increasing etching time. It has been observed experimentally that by increasing the etching time for optical fiber it is possible to create NSOM probes with wider cone angle.

References

1) Dunn, R. C. *Chem. Rev. 1999*, *46*, 2891-2927.
2) Hecht, B. et al. *J. Chem. Phys.* 2000, *112*, 7761-7774 .
3) Novotny and Stephan *Annu. Rev. Phys. Chem.* 2006, *57*, 303–31.
4) A. Ivanov and U. Mescheder *COMSOL Conference Paper* 2012.

Excerpt from the Proceedings of the 2019 COMSOL Conference in Boston