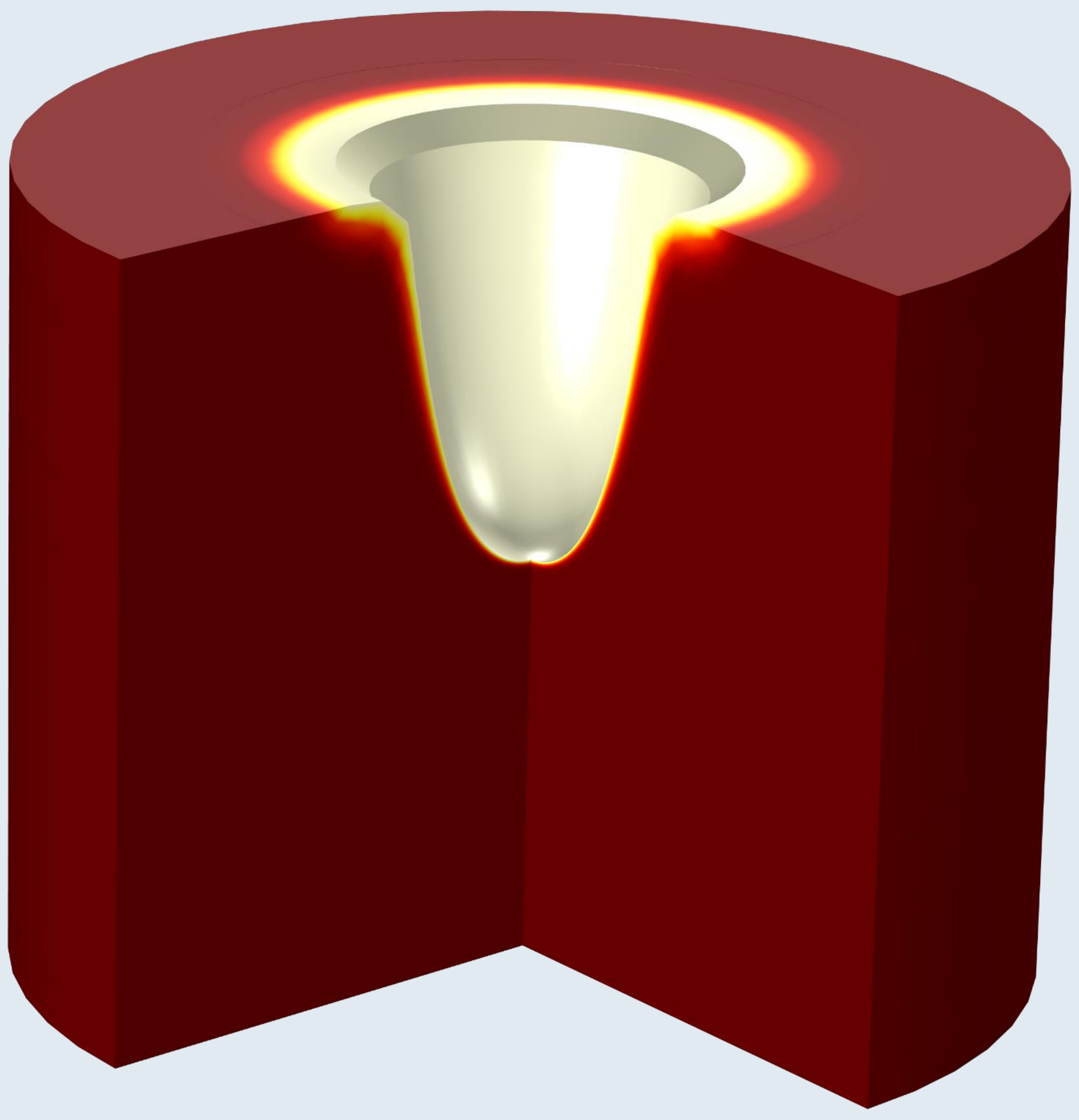


Numerical Modeling of Laser Lithotripsy

Predict the dimensions of a crater (depth, width, volume) generated by the application of a laser on a study material to optimize the lithotripsy process.

A. Menaesse[1], V. Bruyère[2], P. Namy[2], V. Gatineau[1], G. Spiezia[1]
1. EMS, Nyon, Switzerland
2. SIMTEC, Grenoble, France

Introduction & Goals

During a laser lithotripsy procedure, the laser beam is delivered directly to the kidney stone through an optical fiber inserted inside an endoscope. The stone is then destroyed through a combination of thermal, mechanical and chemical processes. Modeling is a convincing approach to provide relevant elements to further master the process. A thermal numerical model with material ablation is developed and presented in this work. Its aim is to predict the depth, radius and volume of the crater formed by the laser impact depending on the operating conditions (laser power, laser beam radius, type of impacted material…). A validation with experimental data is carried out to guarantee the validity of the chosen approach on a various range of operating conditions.

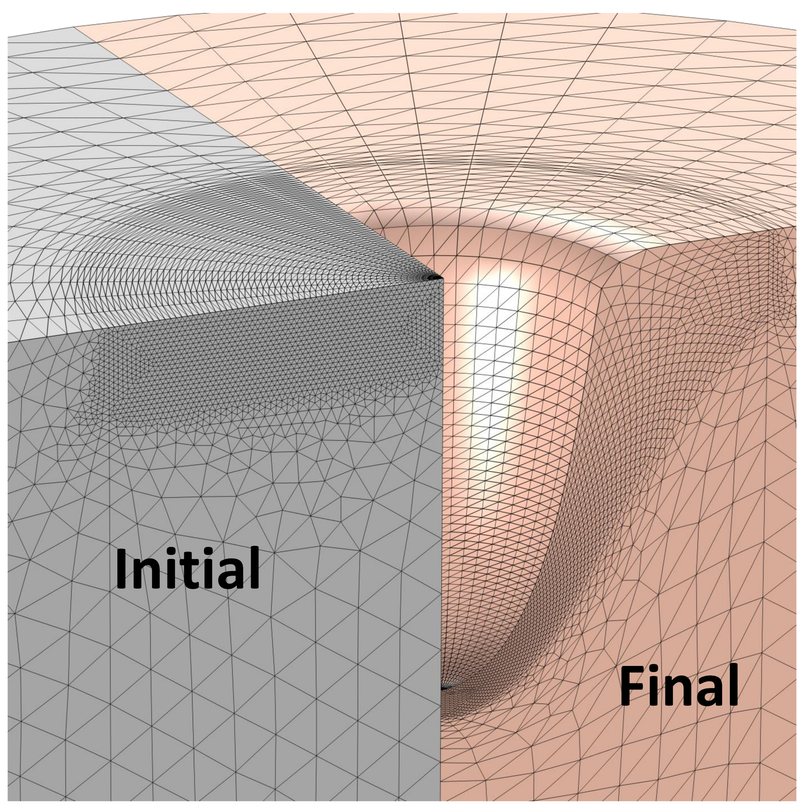
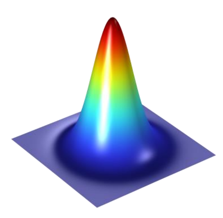


FIGURE 1: Initial and Final Meshes

Heat Transfer

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot [-k\nabla T] = 0$$



Laser Heating:

$$q_{laser} = \frac{4P_{laser} \cdot Abs}{\pi d_0^2} e^{\left(-\frac{4r^2}{d_0^2} + \frac{z}{\delta_z}\right)}$$

Vaporization Process:

$$\rho L_v \boldsymbol{u_{vap}} \cdot \boldsymbol{n} = \underbrace{h(T - T_{vap})}_{\textit{Ablation flux}} \cdot \boldsymbol{n}$$

Methodology

In this approach, only the solid phase is modeled, meaning the fluid around the component (whose interaction is detailed in [Ref. 1]) and the vaporized matter are not geometrically considered. To compute the shape of the solid component after one laser impact and to obtain the resulting crater depth and volume, the assumption that the solid material surface temperature does not significantly exceed a certain threshold temperature, T_{vap}, is made. The “Deformed Geometry” (see Figure 1) and “Heat Transfer in Fluids” interfaces are solved together in a fully coupled way in a 2D-axisymmetric geometry. To obtain precise results and robust convergence, the normal mesh velocity is prescribed using weak constraints.

Results

After numerical validation, the model is used to predict the dimensions of a crater. The latent heat parameter L_v and the threshold temperature T_{vap} sensitivities are studied carefully to calibrate our approach. To validate quantitatively the model, different operating conditions (six pulse energies and six laser beam diameters) are simulated and compared with experimental results. Final crater depths are plotted in Figure 2 for all the configurations, showing reasonable agreement between numerical and experimental results. To take advantage of the possibility offered by COMSOL Multiphysics® to generate a simplified and synthetic interface, an application was generated.

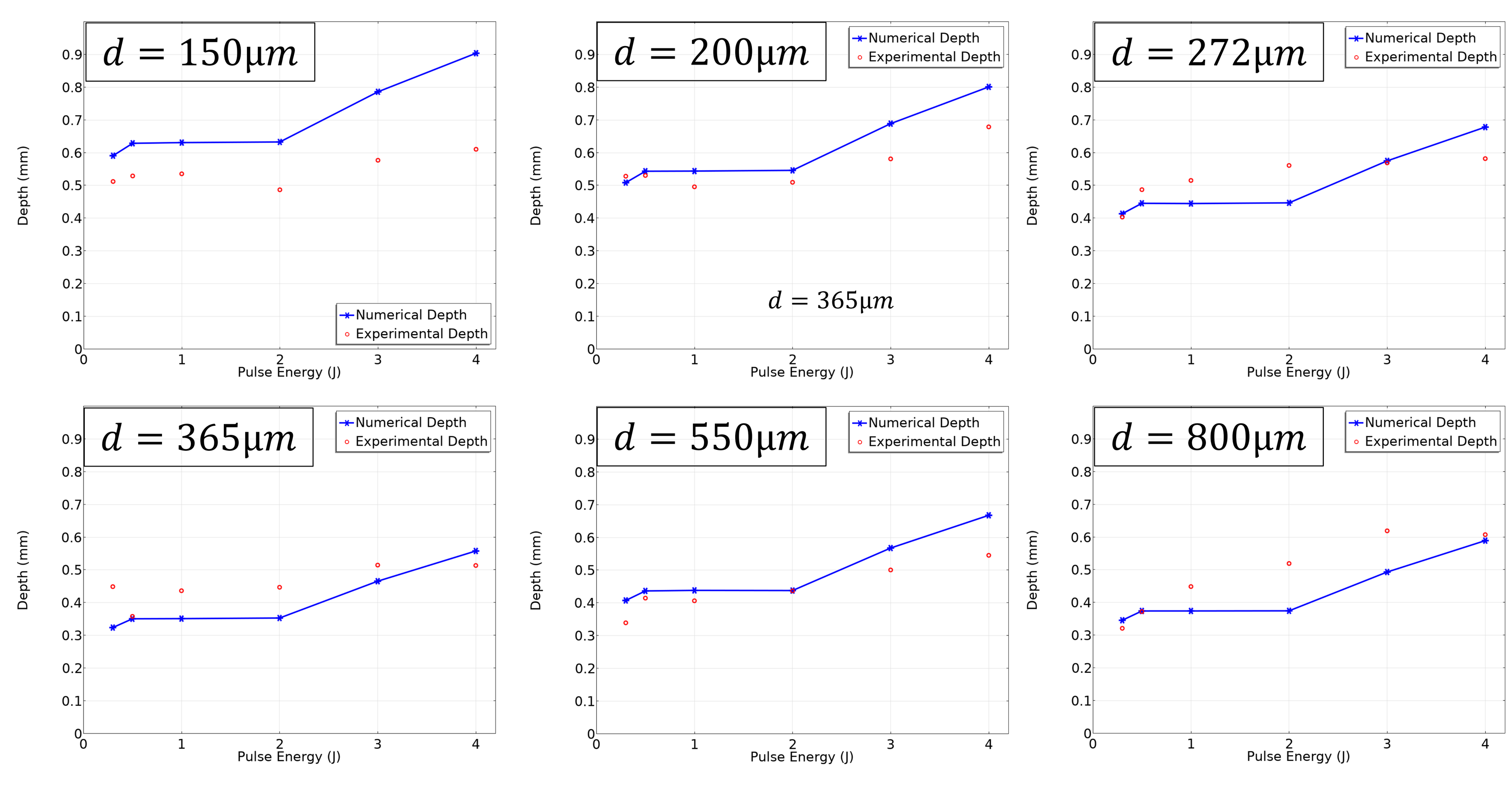


FIGURE 2: Crater depths for different laser beam diameter (d) and pulse energies – Experimental results (red markers), numerical results (blue lines)

REFERENCES

1. V. LEROY, "Bulles d’air dans l’eau : couplage d’oscillateurs harmoniques et excitation paramétrique," Thèse, Université Paris 7, 2004.

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