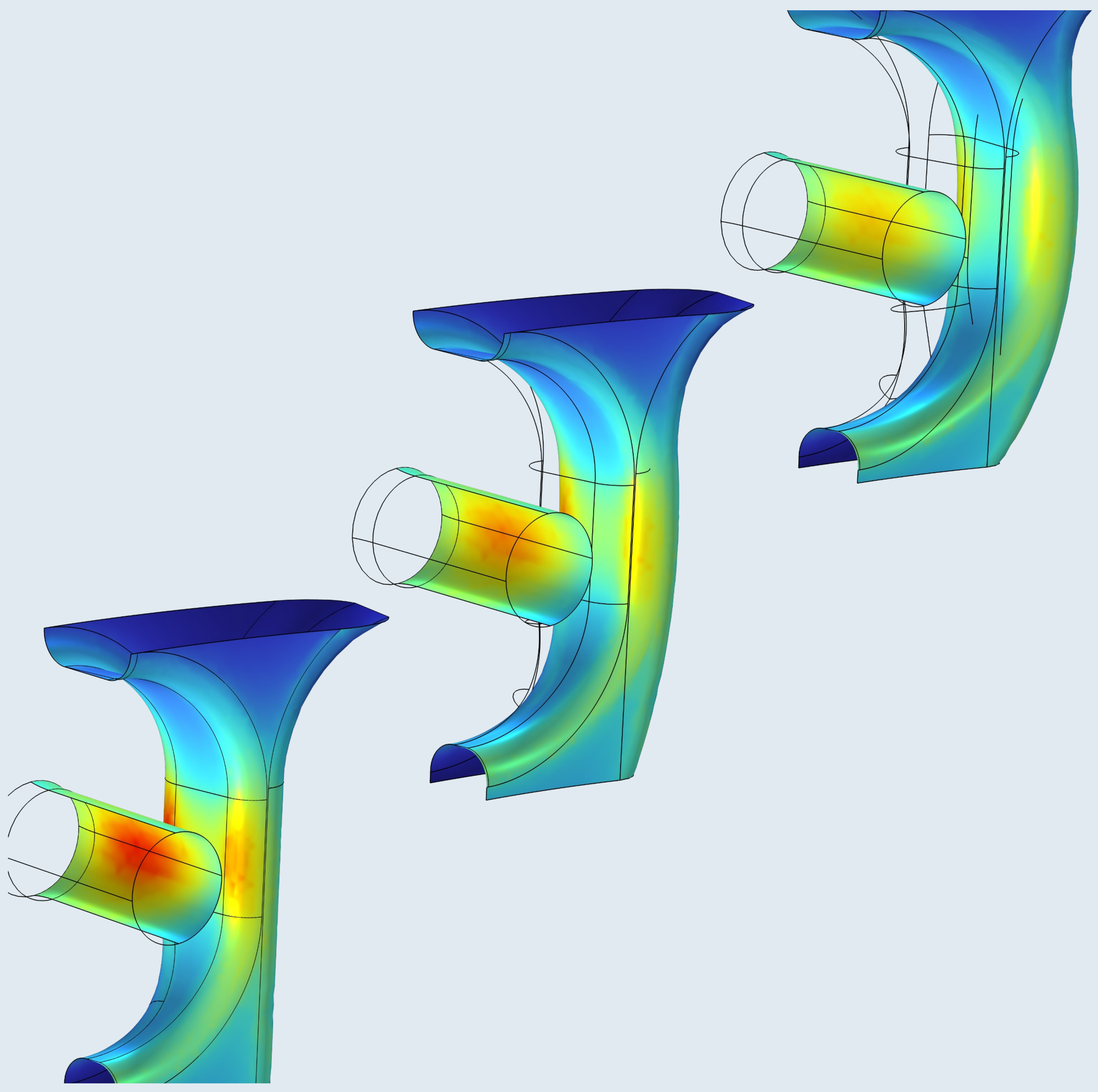

Improving High Voltage Stability of Vacuum Components with COMSOL® Shape Optimization

Electric fields can be excessively high due to geometry effects. Optimizing the geometry shape reduces maximum fields and therefore enhances high voltage stability.

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Introduction

High voltage (HV) stability is an important requirement in many technical areas. The prevention of partial discharges or flashovers implies careful mechanical and electrical design of all components with high electric potential difference towards the surrounding. In the semiconductor industry many machines, like electron beam lithography tools or scanning electron microscopes, rely on this stability. Design rules do exist for simple electrical conductive geometries, but complex 2D and 3D geometries need verification with e.g. finite element methods (FEM) in order to keep geometric field enhancement and therefore electric fields below a certain maximum value. For safety reasons, the maximum electric field is chosen e.g. more than a factor of two lower than the theoretical limit of 20 kV/mm (Ref 1). Using multiple cycles of mechanical design and verification are time consuming, but by utilizing the COMSOL® shape optimizer, this process is accelerated considerably.

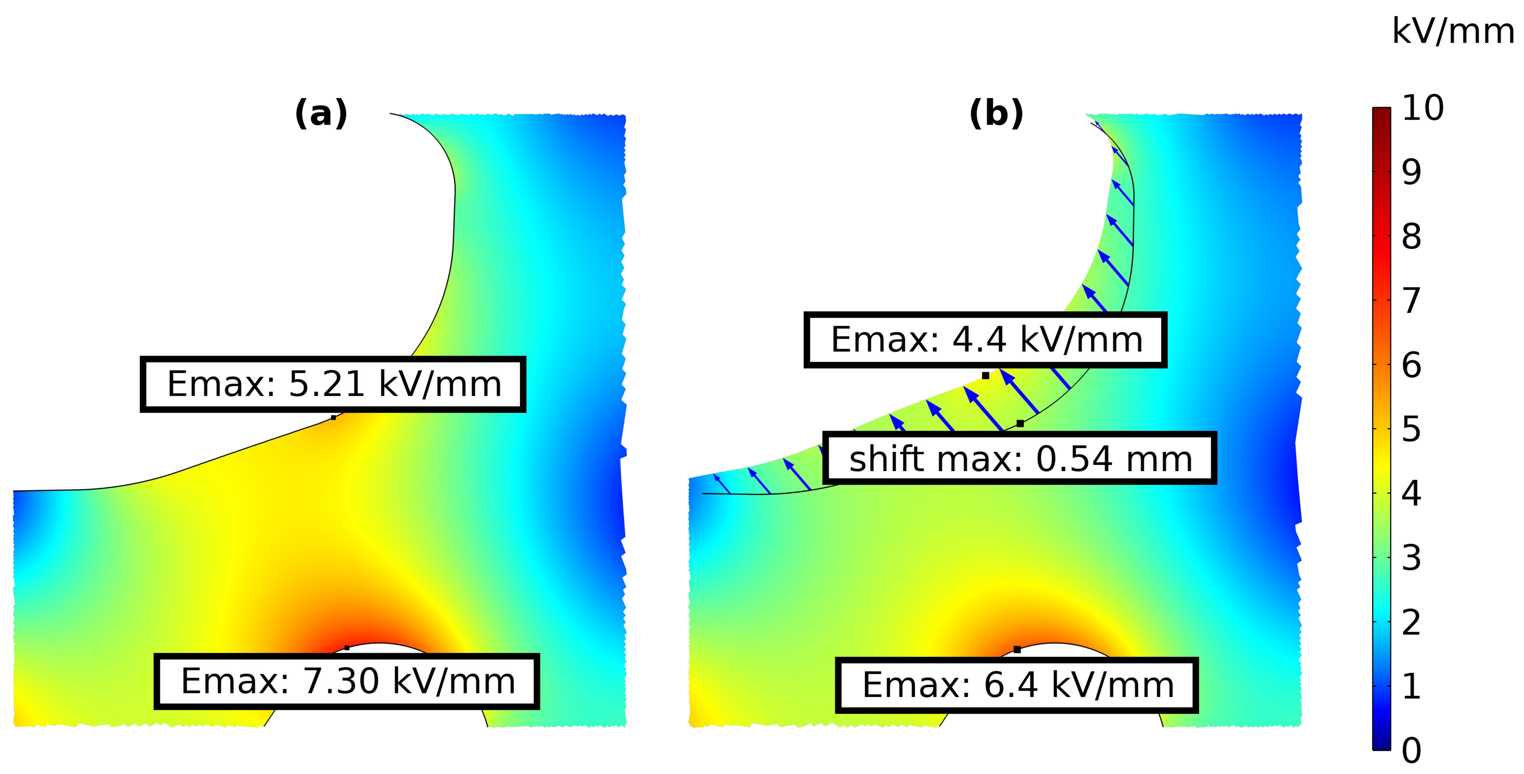

FIGURE 1. 2D axisymmetric shape optimization, minimize max el field norm, surface color data normE in kV/mm. (a) initial geometry and color coded el field, max is 7.3 kV/mm. (b) optimized geometry and color coded el field surface in kV/mm, max dropped to 6.4 kV/mm, max shift is 0.54 mm.

Methodology

A draft 2D or 3D CAD geometry is imported and adapted to FEM needs with the Design Module. The shape optimization requires an objective function which considers maximum electric fields at multiple sites. This is implemented by a pNorm in order to be compatible with the gradient based optimizer:

$$\left(\frac{1}{A}\int |\boldsymbol{E}|^p \, dA\right)^{1/p}$$

A ... *surface area*
$|\boldsymbol{E}|$ ... *el field norm*
p ... *pNorm exponent*, $5-50$

Results

Figure 1 shows cutouts of an axisymmetric configuration, with several kV potential difference between two electrodes. For initial geometry and voltage settings, a max electric field of 7.3 kV/mm occurs at the lower electrode (a). While the shape of the lower electrode is fixed, the adjacent surface is shifted by max 0.54 mm, which reduces the max field by > 10%, to 6.4 kV/mm (b).
Figure 2 shows a shape optimization at a 3D high voltage geometry. A cylindrical rod is placed close to a post structure, with a voltage difference of several tens of kilovolts. The initial analysis (a) yields high electric fields at surfaces with high curvature. While the geometry of the rod is fixed, an optimization bends the posts away from the rod by max 1.1 mm (c). This reduces the overall max field from 9.0 kV/mm by > 20%, to 7.0 kV/mm (b).

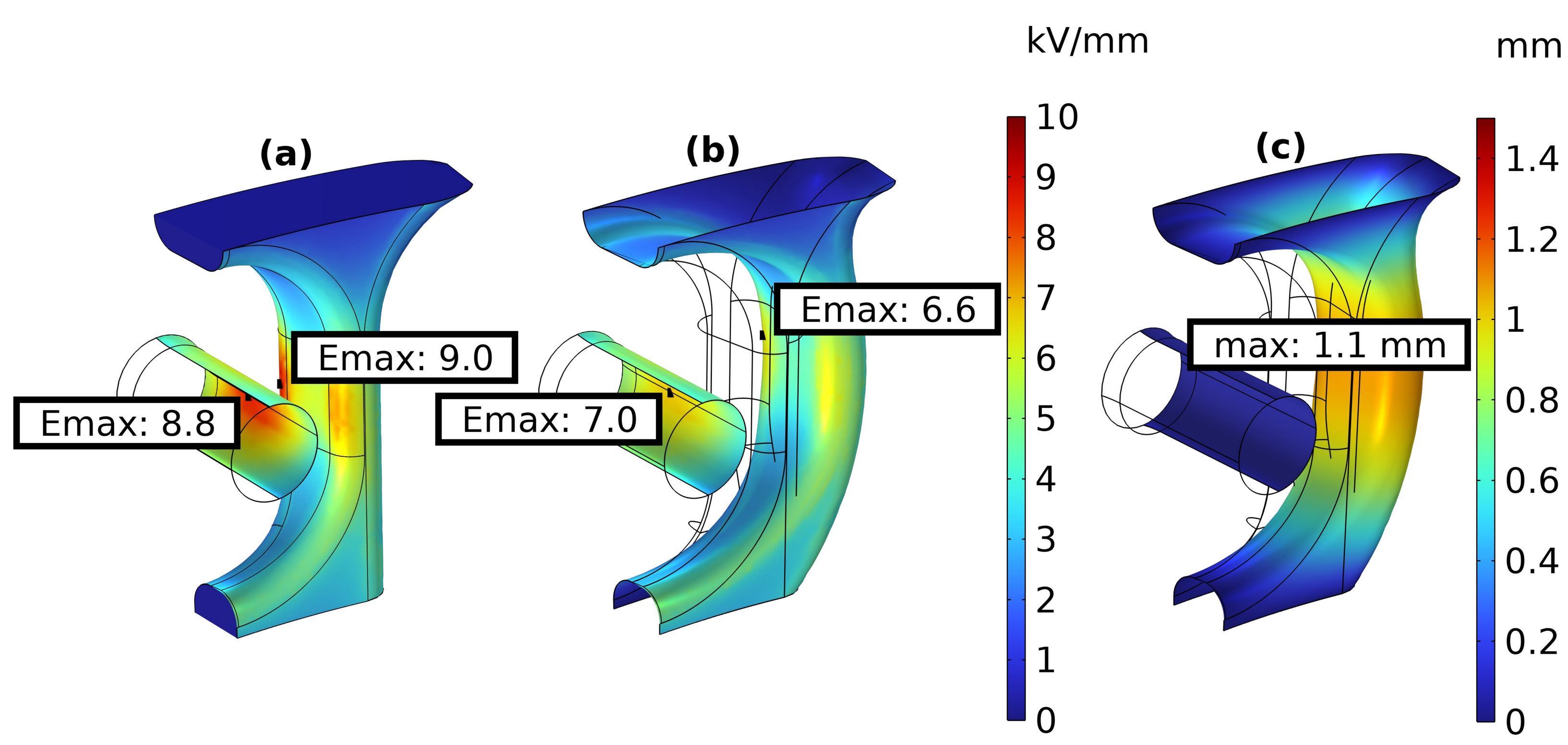

FIGURE 2. 3D shape optimization, minimize max el field norm. Black dots refer to Emax sites, geometry deformation is scaled by factor 5. (a) initial geometry and color coded el field, max is 9.0 kV/mm. (b) optimized geometry and color coded el field surface in kV/mm, max dropped to 7.0 kV/mm. (c) optimized geometry and color coded surface shift, max is 1.1 mm.

REFERENCES

1. S. Giere et al., "HV dielectric strength of shielding electrodes in vacuum circuit-breakers", 20th International Symposium on Discharges and Electrical Insulation in Vacuum - Tours, France, June 30 - July 5, 2002.

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