جامعة خليفة
Khalifa University

ELEN 422 Fall 2024

ELEN 422 High Voltage Engineering

Course Assignment

Computation of Field and Voltage Distributions in Multi-Dielectrics and Dielectrics with Internal Defects

G2

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Problem 1:

A. A 95mmx95 mm square acrylic plate is inserted between two circular, stainless steel parallel-plate electrodes of equal diameters, as shown in Fig. 1. The surrounding medium is air.

1. Build the electrode system in COMSOL.
2. Using the Electrostatics solver, plot the potential distribution (2D color plot) and the equipotential lines in the electrode gap.
3. Plot the electric field distribution in the gap (2 D plot)
4. Plot the electric field along the middle line on the top surface of the acrylic plate, passing by the center of symmetry. What is the maximum value of the tangential field and the resultant field? Identify the point in the dielectric gap corresponding to the maximum field.

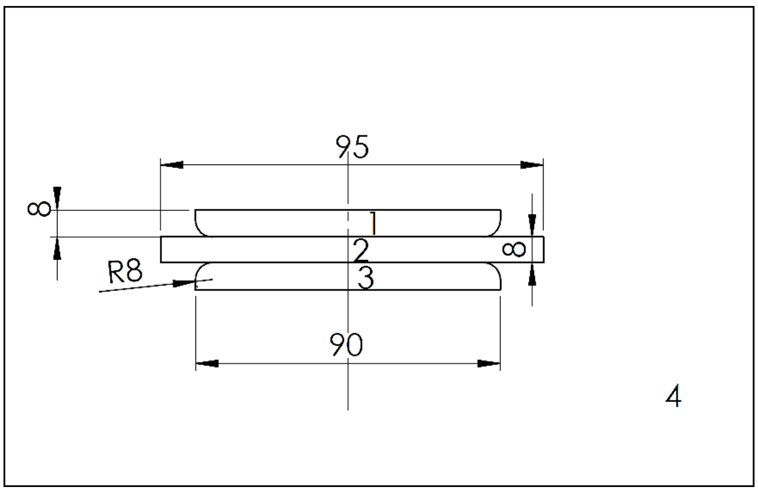

Figure 1. Parallel-plate electrodes and acrylic dielectric plate

ID No	Region	Material	Relative Permittivity
2	Solid Insulator	Acrylic	2.3
4	Surrounding medium	Air	1

Part A Solution:

The electrode system shown in figure 1 was built in COMSOL. The plots obtained for the potential and the electric field distribution are shown in figures 2 and 3.

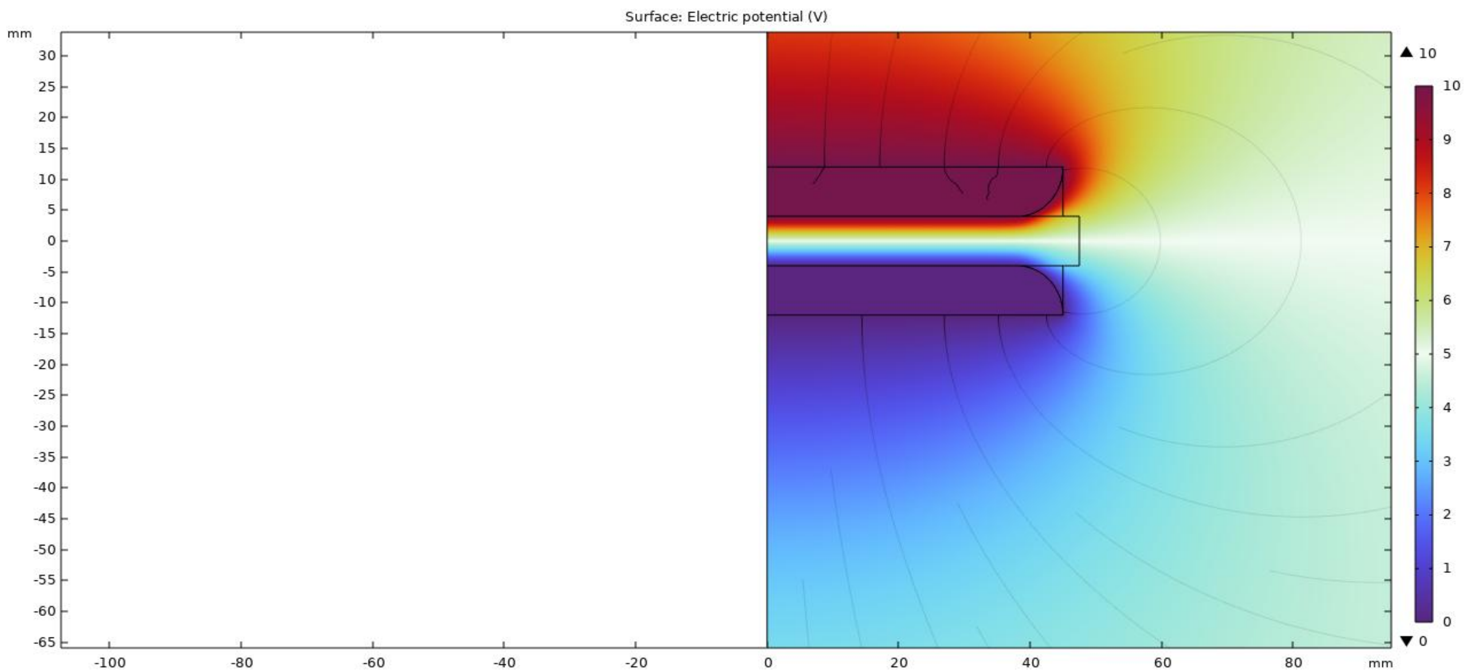

Figure 2. Electric Potential Distribution of the Electrode System Shown in Figure 1

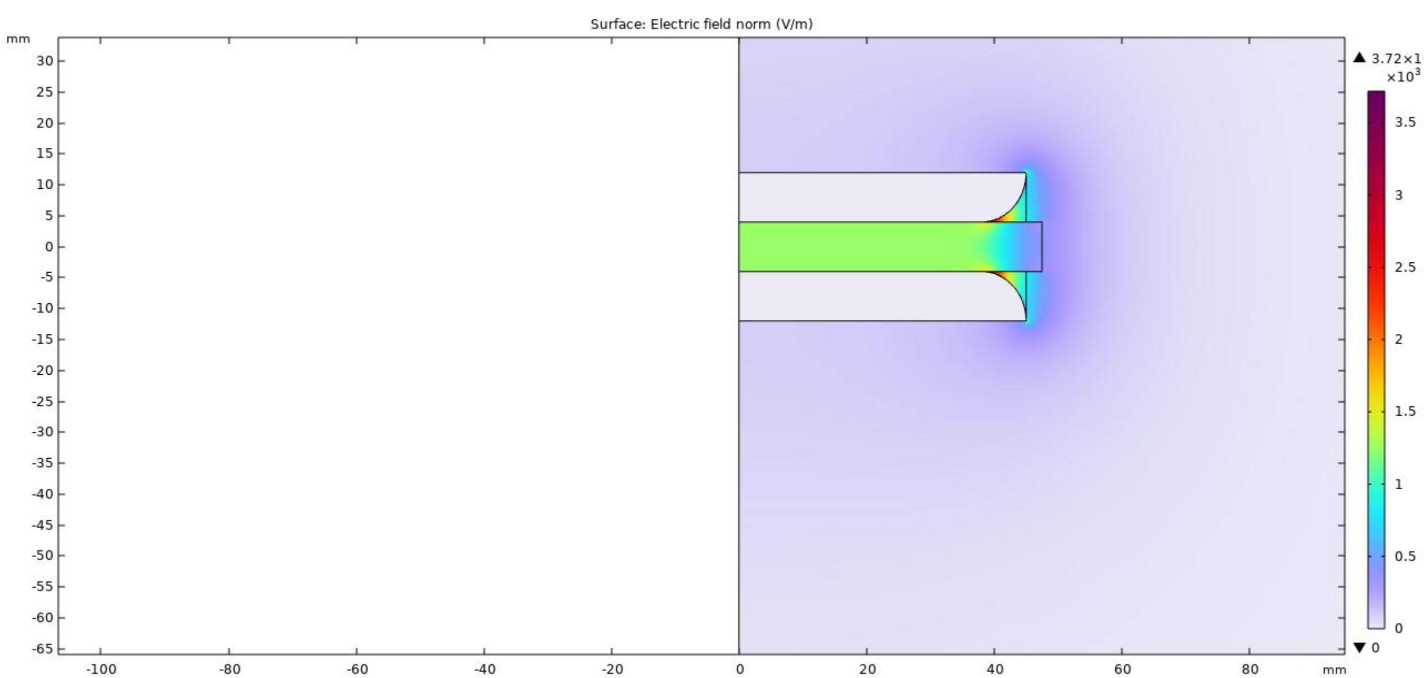

Figure 3. Electric Field Distribution of the Electrode System Shown in Figure 1

The 1D plot of the norm of the electric field along the middle line on the top surface of the acrylic plate, passing by the center of symmetry is shown in figure 4. The 1D plot of the tangential electric field along the same line is shown in figure 5.

Along the line, it is expected that the norm of the electric field should be initially fairly constant, since the electric field is *uniform* in a parallel – plate electrode configuration. The electric field should then increase rapidly near the circular edge. This is because near the circular edge, the distance between the electrode plate and acrylic dielectric is very small and the medium between the two materials is air. Air has a dielectric constant lower than that of the acrylic plate, and the electric field intensity is always greater in the material of the lower permittivity. The electric field in that region can be approximated by $\frac{V}{d_{air}+d_{dielectric}\times\frac{\varepsilon_{air}}{\varepsilon_{dielctric}}}$, according to figure 3, the electric field at that point is specifically 3.72 kV/mm.

The tangential field is expected to be zero initially. This is because the electric field is uniform, with E = $\hat{z}E_z$, the contribution of the tangential component to the resultant field then increases as the electric field becomes less uniform, close to d = 40 mm.

Results shown in figures 4, and 5 show that the electric field is zero over some d, this could be because the cut line was mistakenly defined to cut through the metal electrode material instead of the dielectric. The maximum norm of the electric field is 3.72 kV/mm at d = 38.281 mm. The maximum magnitude of the tangential field component is 0.623 kV/mm at d = 39.98 mm. As expected, the maximum of the fields does not occur at the same point.

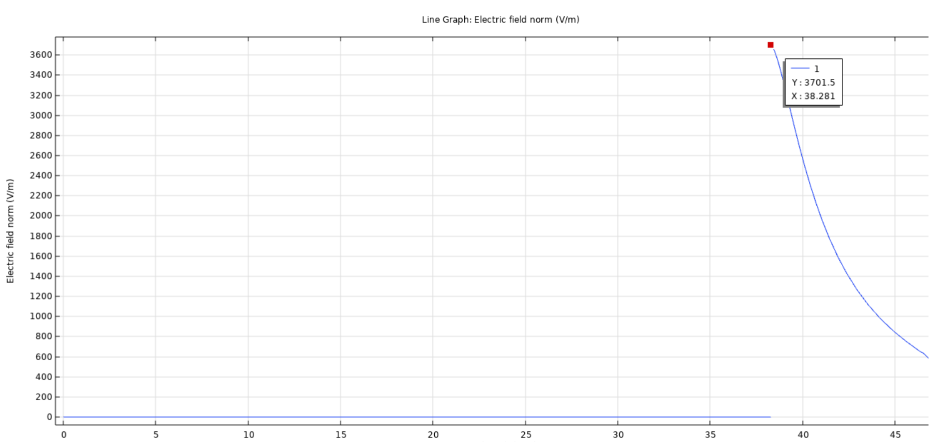

Figure 4. The 1D plot of the norm of the electric field along the middle line on the top surface of the acrylic plate

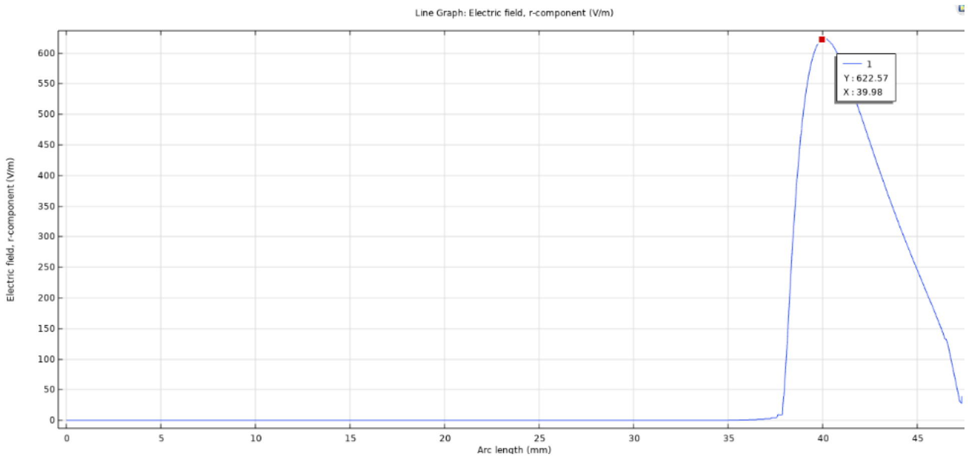

Figure 5. The 1D plot of the tangential component of the electric field along the middle line on the top surface of the acrylic plate

B. If the acrylic plate has a cylindrical air cavity of 1 mm diameter and 2 mm length located in the middle of the plate, on the bottom surface:

5. Plot the 2-D field distribution in the cavity and dielectric.
6. Plot the 1-D electric field strength along 20-mm horizontal lines passing through the cavity's top and bottom surfaces and along a vertical line in the inside wall of the cavity.
7. Deduce the maximum values of the electric field along the three lines and compare them with each other and with the result of case A.4 above. Provide a discussion.

<u>Part B Solution:</u>

The COMSOL simulation of the electrode system (Figure 1) was modified to study the effects of the inclusion of a cavity on the electric field distribution. Figure 6 shows the resulting 2-D field distribution of the system. We can observe that the electric field is strongest inside the cavity and at the circular and sharp edges of the electrode.

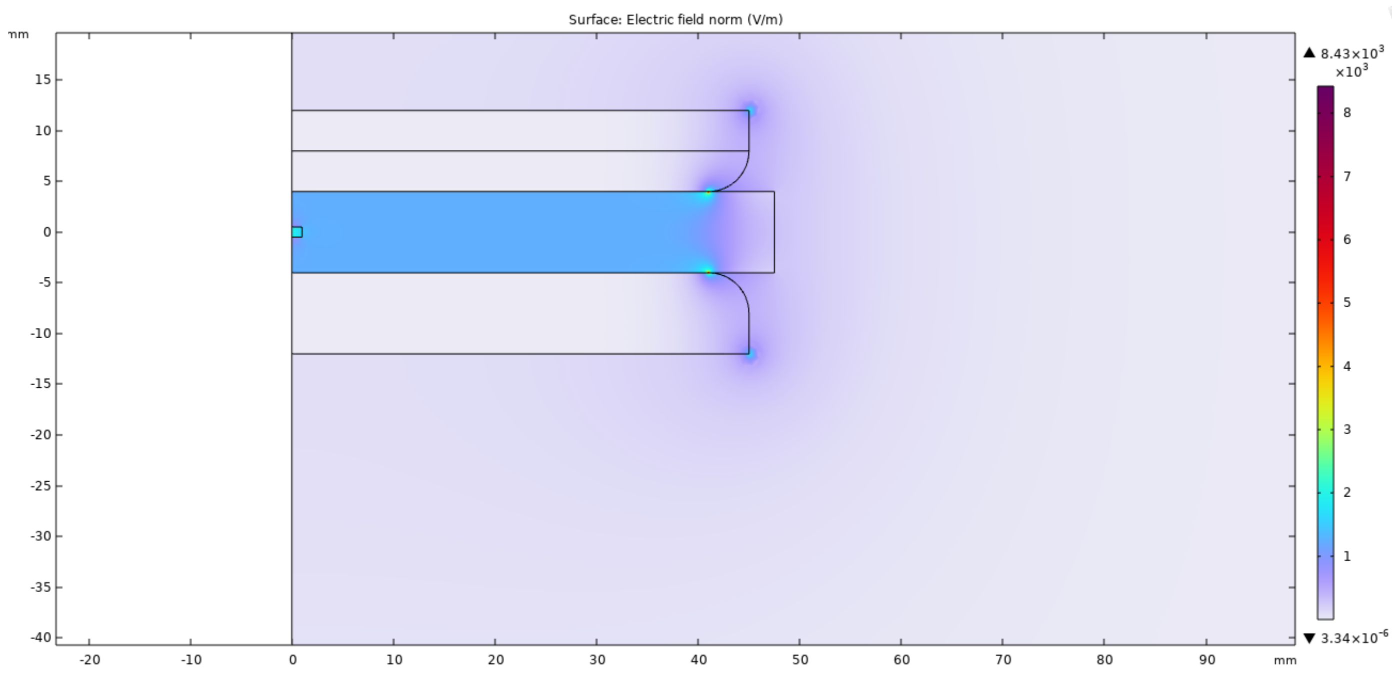

Figure 6. Electric Field Distribution of the Electrode System Shown in Figure 1

The 1D plot of the electric field along 20-mm horizontal lines passing through the cavity's top and bottom surfaces and along a vertical line in the inside wall of the cavity are shown in figures 7-9, respectively.

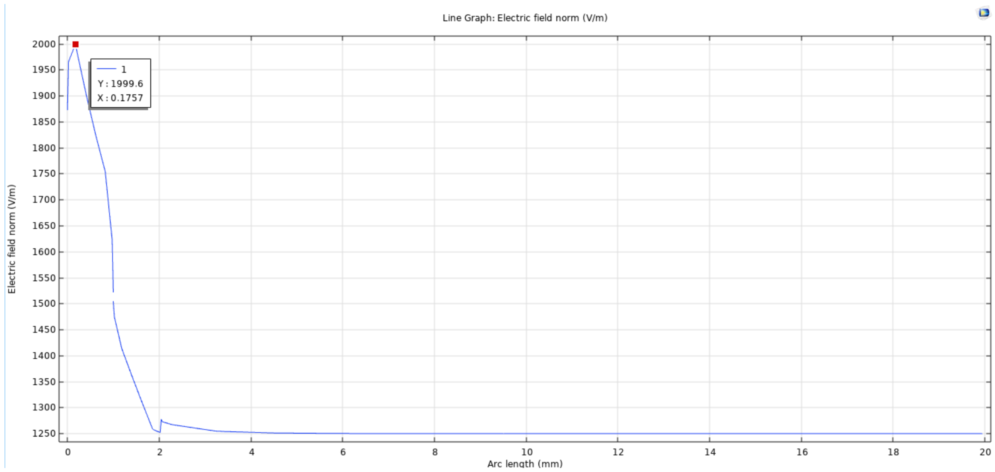

Figure 7. The 1D plot of the electric field along a 20-mm horizontal line passing through the cavity's top surface

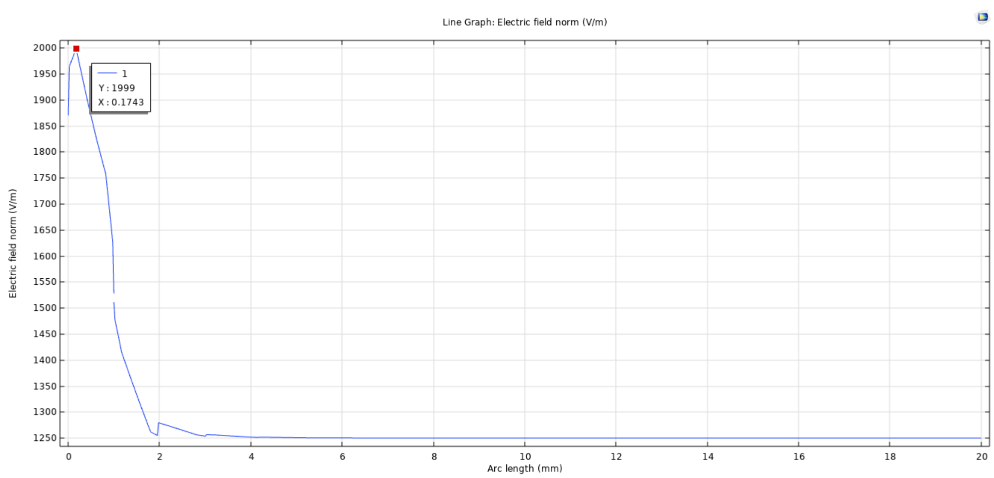

Figure 8. The 1D plot of the electric field along a 20-mm horizontal line passing through the cavity's bottom surface

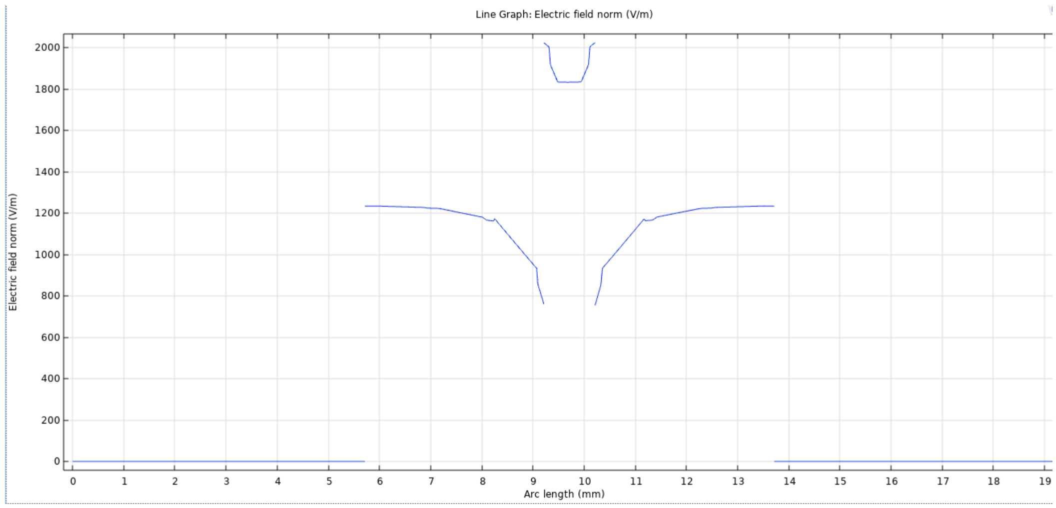

Figure 9. The 1D plot of the electric field along a 20-mm horizontal line passing through the inside wall of the cavity

The electric field inside the cavity can be calculated as given below:

$E_{cavity} = \frac{V}{d_{air}+d_{dielectric}\times\frac{\varepsilon_{air}}{\varepsilon_{dielectric}}} = \frac{10}{2+(8-2)\times\frac{1}{2.3}} = 2.17\ kV/mm$, this result matches the COMSOL simulation result (Figure 6).

The COMSOL results shown in figures 7-8 match the expected result as well. The electric field is greater in the cavity, compared to the dielectric material. Figure 9 shows that the electric field is discontinuous at the boundary between the cavity and the dielectric, and uniform in the cavity and the acrylic plate at distances further from the boundary.

Problem 2:

A high-voltage is applied across a point-plane electrode air gap, with the point electrode at high potential and the plate electrode grounded, as shown in Fig. 10.

1. For an air gap d=8mm, compute and plot the electric potential and field distribution in the gap for and applied voltage of:
   a. V=15 kV
   b. V=25 kV
2. Which of the two voltages causes corona discharge at the tip of the top electrode? (Assume the breakdown strength of air E_0=3kV/mm).
3. A 90x90 mm square acrylic plate of 2 mm thickness is placed on the surface of the bottom electrode. Plot the field distribution in the gap. What is the maximum field intensity at the electrode tip for the applied voltage of 25 kV? Compare with the case without dielectric plate and discuss.

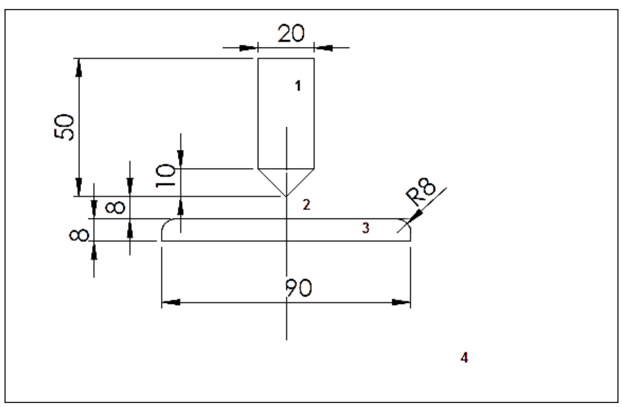

Figure 10. Point-plate electrode gap

Solution:

The electrode system shown in figure 10 was built in COMSOL. Figures 11 and 12 show the resulting electric field distribution when a voltage of 15 kV and 25 kV was applied, respectively. The maximum electric field is displayed at the top right of the figures. Since the maximum electric fields for both the voltages, $E_{1,\,max}$ = 3.82 kV/mm, and $E_{2,\,max}$ = 6.37 kV/mm exceed the dielectric strength of air, E_0 =3kV/mm, therefore, both voltages cause a corona discharge at the tip of the electrode (the point at which the electric field is maximum).

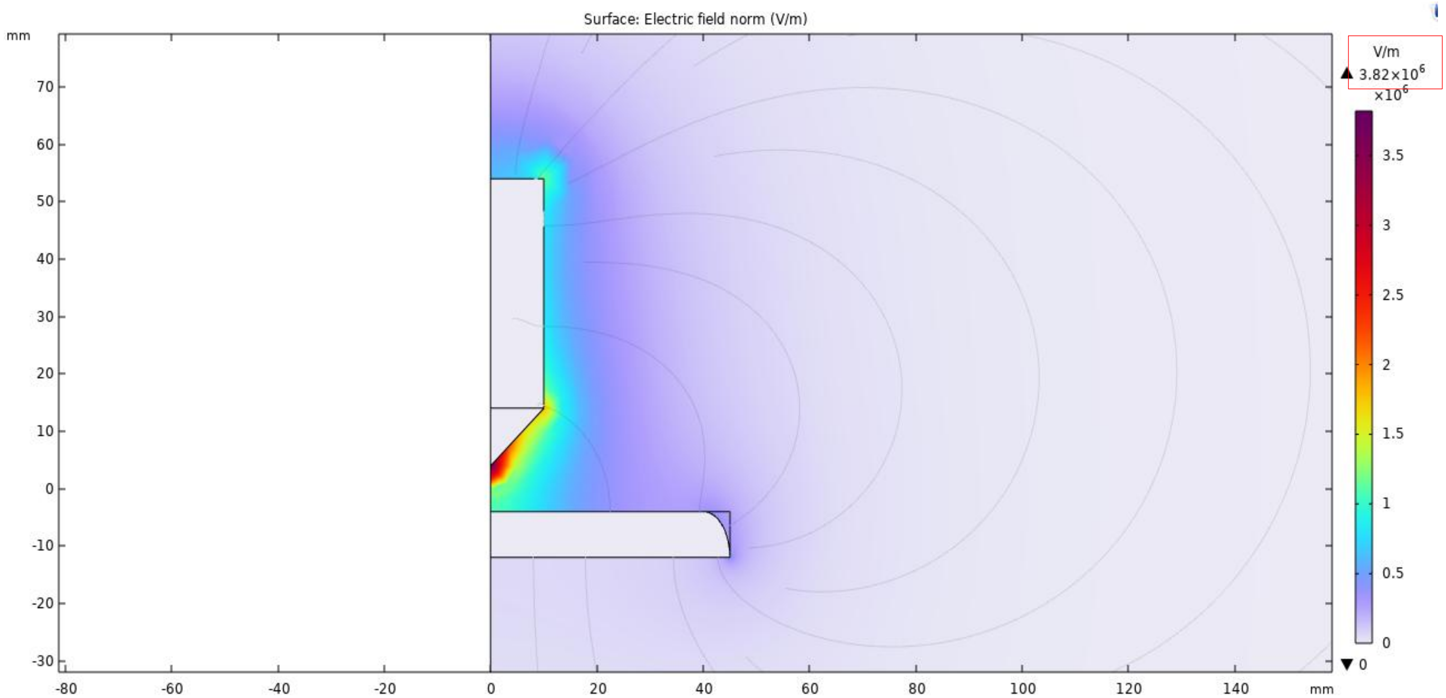

Figure 11. Electric Potential Distribution of the Electrode System Shown in Figure 10 for V = 15 kV

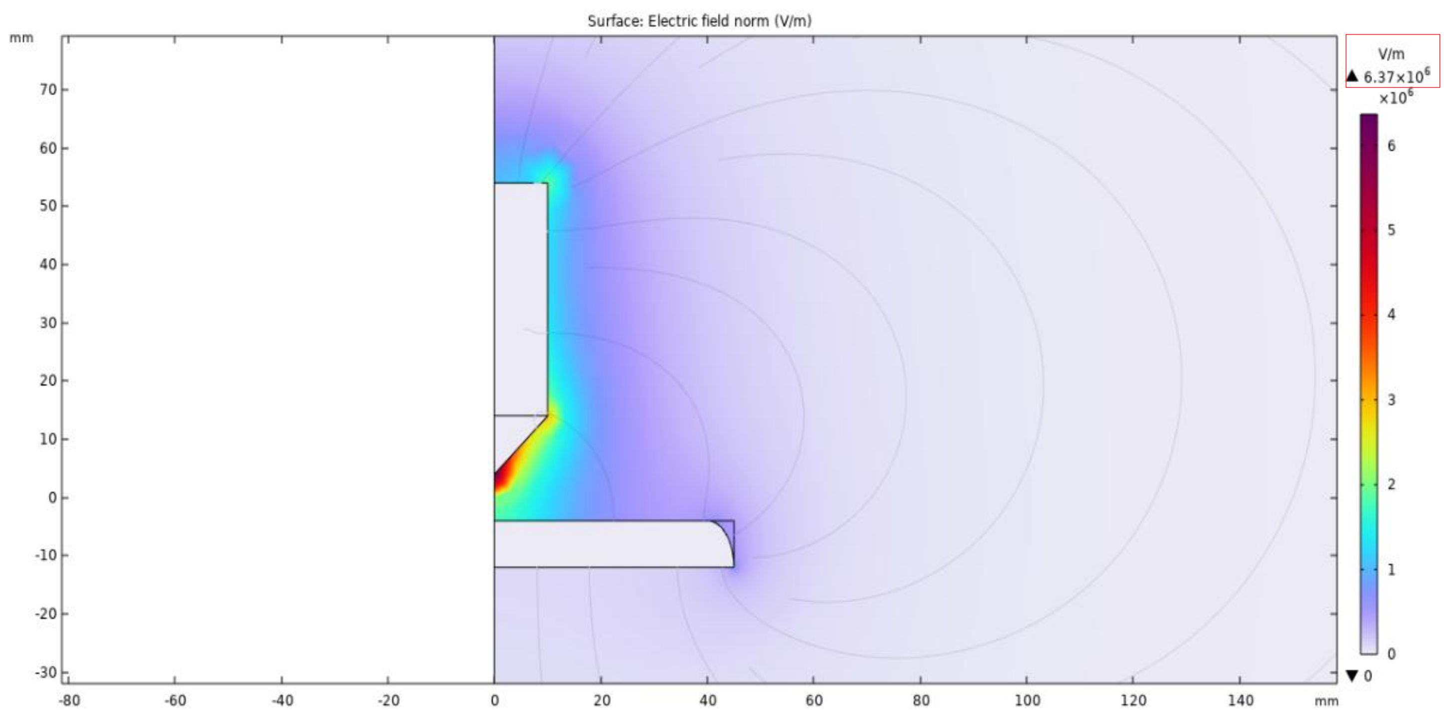

Figure 12. Electric Potential Distribution of the Electrode System Shown in Figure 10 for V = 25 kV

Keeping the applied voltage at V = 15 kV, when a 90x90 mm square acrylic plate of 2 mm thickness was placed on the surface of the bottom electrode, the electric field distribution of the electrode system changed as shown in figure 13. The maximum electric field at the tip of the electrode increased to $E_{1', max}$ = 5.56 kV/mm. This is because the insertion of the dielectric (1) reduced the distance (d) of the air dielectric (between the tip of the top electrode and the acrylic plate). (2) the dielectric constant of the acrylic plate is higher than that of air, $\frac{\varepsilon_{r,acrylic}}{\varepsilon_{r,air}} > 1$, therefore, the electric field in air (including at the tip of the electrode) is expected to increase; the intensity of the electric field is always higher in the material of lower permittivity (air).

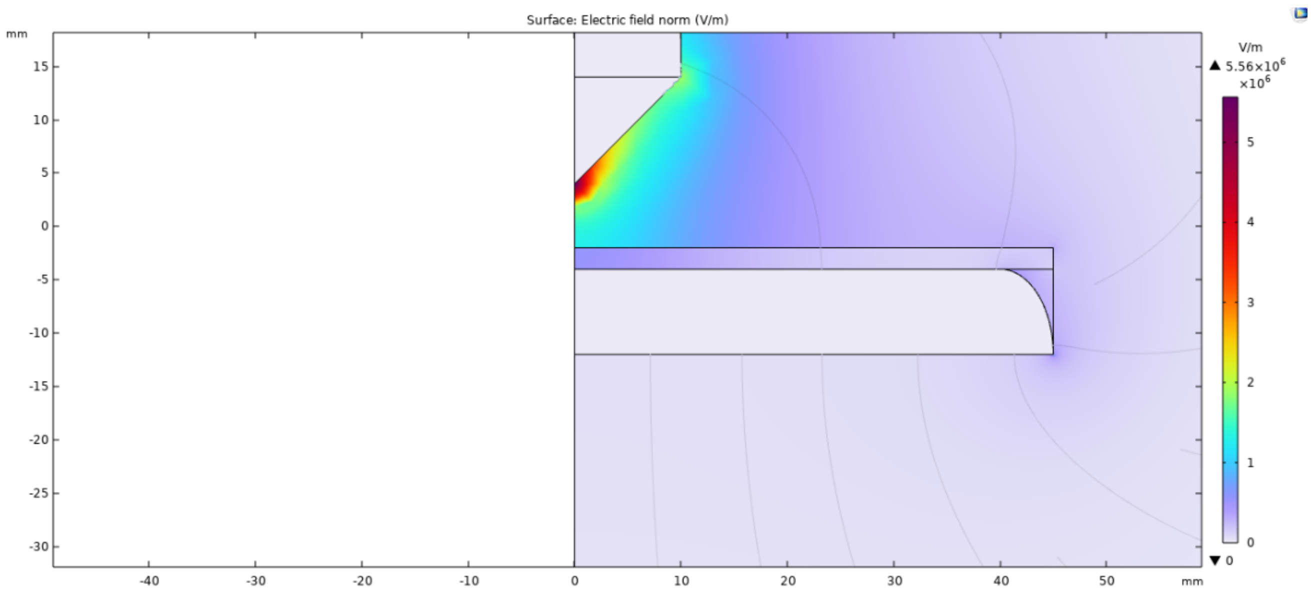

Figure 13. Electric Potential Distribution of the Electrode System Shown in Figure 10 for V = 15 kV when an acrylic plate of 2 mm thickness was inserted in top of the electrode plate.