Electric field sensing with a scanning fiber-coupled quantum dot - Supplemental Material

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A cylindrical dielectric wire in a uniform electric field produces an internal depolarization field. This effect is shown in Figure S1. Under the hypothesis of a uniform polarization of the dielectric parallel to the external field, the electric field at a point h along the long axis of the wire is reduced by a depolarization field anti-parallel to the external field. This reduction is substantially different for external fields parallel and perpendicular to the wire axis.

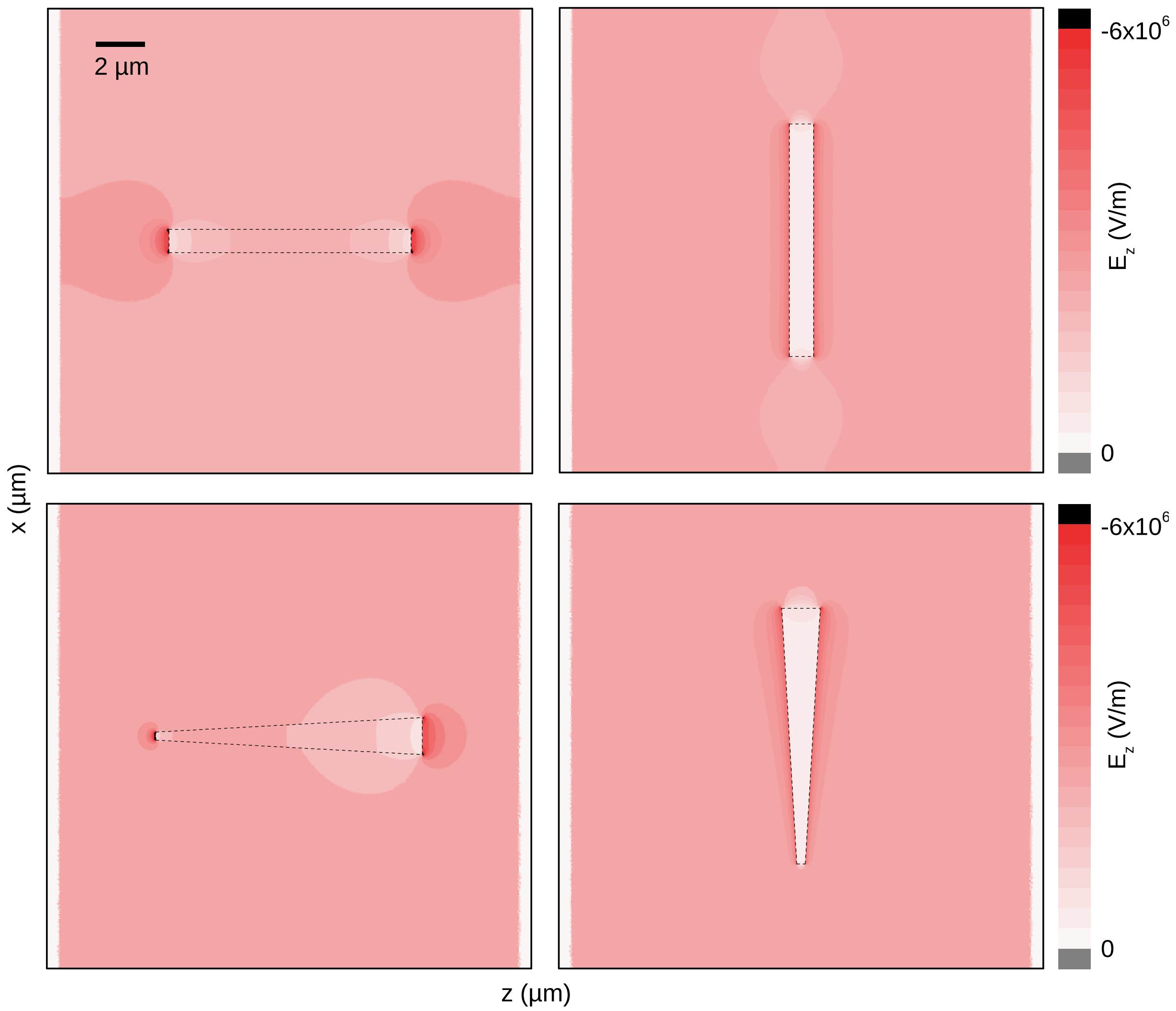

FIG. S1: Simulated values of E_z for a 11 μm long GaAs wire between two planar electrodes 20 μm apart. Plots show the xz-plane, which cuts through the center of the wire. A cylindrical wire with its axis (a) parallel and (b) perpendicular to the external field and a tapered wire with its axis (c) parallel and (d) perpendicular to the field.

In order to calculate this effect, we define the angles $\phi_{1,2}(h)$ as shown in Fig S2 a):

$$\cos(\phi_1) = \frac{h}{\sqrt{(b/2)^2 + h^2}}, \;\; \cos(\phi_2) = \frac{L-h}{\sqrt{(D/2)^2 + (L-h)^2}} \tag{1}$$

where b and D are the diameter of the bottom and top facets, respectively. By integrating over the entire surface of the wire, we obtain a compact formula for the reduced electric field $\vec{E}$ along the axis of the wire as a function of the position h along the axis:

$$\vec{E}(\phi_{1,2}) = \frac{1}{\gamma(\phi_1,\phi_2)(\varepsilon_r - 1) + 1}\vec{E}_0 \tag{2}$$

where $\varepsilon_r = 12.9$ is the dielectric constant of the wire, $\gamma(\phi_1,\phi_2) = \frac{1}{4}\big(\cos(\phi_1) + \cos(\phi_2)\big) \equiv \gamma^{\perp}$ for the external field perpendicular to the axis of the cylinder and $\gamma(\phi_1,\phi_2) = \sin^2\left(\frac{\phi_1}{2}\right) + \sin^2\left(\frac{\phi_2}{2}\right) \equiv \gamma^{\parallel}$ for the field parallel to the axis.

In a real system, however, the hypothesis of the uniform and unidirectional polarization does not hold. As a result, the solution deviates from the analytical description of Equation 2. A finite element simulation (COMSOL) can produce a more realistic result without this simplifying assumption (Figure S2 b,c). The simulated (solid lines) and theoretical (dashed lines) values of the electric field inside a cylindrical and tapered wire are plotted as a function of h in the case of the external field parallel (blue) and perpendicular (orange and red) to the wire axis.

In the case of our experimental setup, the field is also not uniform along z. In a first approximation, however, the electric field inside the wire is obtained by just replacing the uniform field $\vec{E}_0$ in Eq. 2 with a space decaying form, resulting in a curve similar to the one simulated and shown in Fig. 4b in the main text.

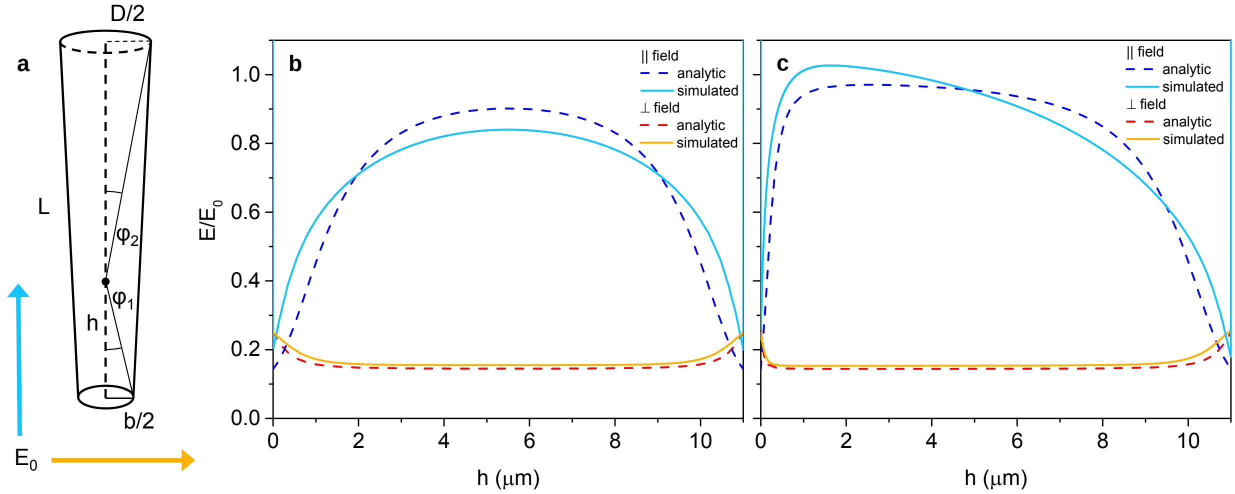

FIG. S2: (a) geometry of the wire and definition of the angles $\phi_{1,2}$. (b),(c) Normalized values of the electric field inside a cylindrical wire (b) with $L = 11$ μm and $D = 1.5$ μm, and tapered wire (c) with $b = 250$ nm, as a function of position along the axis of the wire. The solid lines correspond to exact simulations, while dashed lines are values given by Equation 2. Red and orange curves correspond to the perpendicular configuration and blue lines correspond to the parallel one.