Manuscript ID: **jp-2012-10676s**

Title: **Local dielectric environment dependent local electric field enhancement in double concentric silver nanotubes**

Corresponding author: **Jun-wu Zhao**

Submitted for publication in: **The Journal of Physical Chemistry C**

Supplementary material

The solution for the local electric field in each region of the double nanotube could be derived from Laplace's equation under cylindrical coordinates. In this system, the nanostructure has been divided into five regions. The electrostatic potential in each region from inner dielectric core to outer surrounding (*m*=1,2,3,4,5) could be obtained as $\varphi_m(r,\phi)=(A_m r+\frac{C_m}{r}-E_0 r)\cos\phi$, where *r* denotes the radial distance and ϕ denotes the polar angle. The boundary conditions at the cylinder surface must be specified so that the potential in each region can be determined. The boundary conditions should be written as $\varphi_1(r_1,\phi)=\varphi_2(r_1,\phi)$, $\varphi_2(r_2,\phi)=\varphi_3(r_2,\phi)$, $\varphi_3(r_3,\phi)=\varphi_4(r_3,\phi)$ and $\varphi_4(r_4,\phi)=\varphi_5(r_4,\phi)$. Furthermore, there must be continuity of the normal component of the displacement field, i.e., $\varepsilon_1(\frac{\partial\varphi_1}{\partial r})_{r_1}=\varepsilon_2(\frac{\partial\varphi_2}{\partial r})_{r_1}$, $\varepsilon_2(\frac{\partial\varphi_2}{\partial r})_{r_2}=\varepsilon_3(\frac{\partial\varphi_3}{\partial r})_{r_2}$, $\varepsilon_3(\frac{\partial\varphi_3}{\partial r})_{r_3}=\varepsilon_4(\frac{\partial\varphi_4}{\partial r})_{r_3}$ and $\varepsilon_4(\frac{\partial\varphi_4}{\partial r})_{r_4}=\varepsilon_5(\frac{\partial\varphi_5}{\partial r})_{r_4}$. In the inner core region, $\varphi_1=-E_0 r\cos\phi$, thus C_1=0; in the outer surrounding region, far from the gold tubes, we must recover the potential $\varphi_5=-E_0 r\cos\phi$, thus giving A_5=0. And then the electric field in each region of the nanostructure can be obtained with $\vec{E}(r,\phi)=-\nabla\varphi(r,\phi)$.

$$\vec{E}_1=(1-\frac{A_1}{E_0})\vec{E}_0 \tag{1}$$

$$\vec{E}_2=(1-\frac{A_2}{E_0})\vec{E}_0+\frac{C_2}{r^2}(\cos\phi\vec{e}_r+\sin\phi\vec{e}_\phi) \tag{2}$$

$$\vec{E}_3=(1-\frac{A_3}{E_0})\vec{E}_0+\frac{C_3}{r^2}(\cos\phi\vec{e}_r+\sin\phi\vec{e}_\phi) \tag{3}$$

$$\vec{E}_4=(1-\frac{A_4}{E_0})\vec{E}_0+\frac{C_4}{r^2}(\cos\phi\vec{e}_r+\sin\phi\vec{e}_\phi) \tag{4}$$

$$\vec{E}_5 = \vec{E}_0 + \frac{C_5}{r^2}(\cos\phi\vec{e}_r + \sin\phi\vec{e}_\phi) \tag{5}$$

where

$$A_1 = \frac{E_0\left\{\begin{array}{l} r_1^2(\varepsilon_1-\varepsilon_2)(r_2^2(\varepsilon_2+\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+r_3^2(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4- \\ \varepsilon_5)+r_4^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5)))+r_2^2(r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+ \\ r_3^2(r_3^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_1(\varepsilon_2+\varepsilon_3)(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5)+ \\ \varepsilon_2(\varepsilon_2(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5)+\varepsilon_3(\varepsilon_4(\varepsilon_4-15\varepsilon_5)+\varepsilon_3(\varepsilon_4+\varepsilon_5)))))) \end{array}\right\}}{\eta} \tag{6}$$

$$A_2 = \frac{E_0\left\{\begin{array}{l} r_1^2(\varepsilon_1-\varepsilon_2)(r_2^2(\varepsilon_2+\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+r_3^2(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4- \\ \varepsilon_5)+r_4^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5)))+r_2^2(\varepsilon_1+\varepsilon_2)(r_2^2(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+ \\ r_3^2(r_3^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_2(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5)+\varepsilon_3(\varepsilon_4(\varepsilon_4-7\varepsilon_5)+\varepsilon_3(\varepsilon_4+\varepsilon_5))))) \end{array}\right\}}{\eta} \tag{7}$$

$$A_3 = \frac{E_0\left\{\begin{array}{l} r_1^2(\varepsilon_1-\varepsilon_2)(r_2^2(\varepsilon_2+\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+r_3^2(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4- \\ \varepsilon_5)+r_4^2(\varepsilon_4(\varepsilon_4-3\varepsilon_5)+\varepsilon_3(\varepsilon_4+\varepsilon_5))))+r_2^2(\varepsilon_1+\varepsilon_2)(r_2^2(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+ \\ r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+r_3^2(\varepsilon_2+\varepsilon_3)(r_3^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_4(\varepsilon_4-3\varepsilon_5)+\varepsilon_3(\varepsilon_4+\varepsilon_5)))) \end{array}\right\}}{\eta} \tag{8}$$

$$A_4 = -\frac{E_0}{\varepsilon_4+\varepsilon_5}\left\{\varepsilon_5-\varepsilon_4+\frac{\left\{\begin{array}{l} 2(r_2^2(\varepsilon_1+\varepsilon_2)(r_3^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3+\varepsilon_4))+ \\ r_1^2(\varepsilon_1-\varepsilon_2)(r_3^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3+\varepsilon_4)))(\varepsilon_4-\varepsilon_5)\varepsilon_5 \end{array}\right\}}{\zeta}\right\} \tag{9}$$

$$C_2 = \frac{8E_0 r_1^2 r_2^2 r_3^2 r_4^2(\varepsilon_1-\varepsilon_2)\varepsilon_3\varepsilon_4\varepsilon_5}{\eta} \tag{10}$$

$$C_3 = \frac{4E_0 r_2^2 r_3^2 r_4^2(r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2+\varepsilon_3))\varepsilon_4\varepsilon_5}{\eta} \tag{11}$$

$$C_4 = \frac{-E_0\left\{\begin{array}{l} 2r_4^2(r_2^2(\varepsilon_1+\varepsilon_2)(r_3^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3+\varepsilon_4))+ \\ r_1^2(\varepsilon_1-\varepsilon_2)(r_3^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3+\varepsilon_4)))\varepsilon_5 \end{array}\right\}}{\zeta} \tag{12}$$

$$C_5 = E_0 r_4^2\left\{\frac{\varepsilon_4-\varepsilon_5}{\varepsilon_4+\varepsilon_5}-\frac{2\varepsilon_4}{\varepsilon_4+\varepsilon_5}\cdot\frac{\left\{\begin{array}{l} 2(r_2^2(\varepsilon_1+\varepsilon_2)(r_3^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3+\varepsilon_4))+ \\ r_1^2(\varepsilon_1-\varepsilon_2)(r_3^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3+\varepsilon_4)))\varepsilon_5 \end{array}\right\}}{\zeta}\right\} \tag{13}$$

$$\begin{array}{l} \eta = r_1^2(\varepsilon_1-\varepsilon_2)(r_2^2(\varepsilon_2+\varepsilon_3)(r_3^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+r_3^2(\varepsilon_2- \\ \varepsilon_3)(r_3^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5)))+r_2^2(\varepsilon_1+\varepsilon_2)(r_2^2(\varepsilon_2-\varepsilon_3)(r_3^2(\varepsilon_3+ \\ \varepsilon_4)(\varepsilon_4-\varepsilon_5)+r_4^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4+\varepsilon_5))+r_3^2(\varepsilon_2+\varepsilon_3)(r_3^2(\varepsilon_3-\varepsilon_4)(\varepsilon_4-\varepsilon_5)+ \\ r_4^2(\varepsilon_3+\varepsilon_4)(\varepsilon_4+\varepsilon_5))) \end{array} \tag{14}$$

$$\zeta = (-r_2^2(\varepsilon_1+\varepsilon_2)(r_3^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3+\varepsilon_4))-r_1^2(\varepsilon_1-\varepsilon_2)(r_3^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_2^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3+\varepsilon_4)))(\varepsilon_4-\varepsilon_5)-\frac{r_4^2}{r_3^2}(r_1^2(\varepsilon_1-\varepsilon_2)(r_2^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_3^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3+\varepsilon_4))+r_2^2(\varepsilon_1+\varepsilon_2)(r_2^2(\varepsilon_2-\varepsilon_3)(\varepsilon_3-\varepsilon_4)+r_3^2(\varepsilon_2+\varepsilon_3)(\varepsilon_3+\varepsilon_4)))(\varepsilon_4+\varepsilon_5) \quad (15)$$

The double nanotube could be regressed to a single nanotube by just setting the dielectric constant as $\varepsilon_3=\varepsilon_4=\varepsilon_5$. And then the Eqs. (6)- (15) change as follows,

$$A_1 = \frac{E_0 r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1(\varepsilon_2+\varepsilon_3)+\varepsilon_2(\varepsilon_2-3\varepsilon_3))}{r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} \quad (16)$$

$$A_2 = \frac{E_0 r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)}{r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} \quad (17)$$

$$A_3 = 0 \quad (18)$$

$$A_4 = 0 \quad (19)$$

$$C_2 = \frac{2E_0 r_1^2 r_2^2(\varepsilon_1-\varepsilon_2)\varepsilon_3}{r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} \quad (20)$$

$$C_3 = \frac{E_0 r_2^2(r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2+\varepsilon_3))}{r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} \quad (21)$$

$$C_4 = \frac{E_0 r_2^2(r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2+\varepsilon_3))}{r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} = C_3 \quad (22)$$

$$C_5 = \frac{E_0 r_2^2(r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2+\varepsilon_3))}{r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)} = C_3 \quad (23)$$

$$\eta = 4r_1^2 r_3^2 r_4^2 \varepsilon_3^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+4r_2^2 r_3^2 r_4^2 \varepsilon_3^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3) \quad (24)$$

$$\zeta = -4\varepsilon_3\varepsilon_3 r_4^2(r_1^2(\varepsilon_1-\varepsilon_2)(\varepsilon_2-\varepsilon_3)+r_2^2(\varepsilon_1+\varepsilon_2)(\varepsilon_2+\varepsilon_3)) \quad (25)$$

By taking the Eqs. (16)- (23) into the Eqs. (1)-(5), one can obtain the electric field in each region of a single metal nanotube, which are in agreement with the previous work [Zhu, J. *Mater. Sci. Eng. A* **2007**, 454-455, 685].