

Supplementary information:

1. Theory of charge shifting amount.

In this section, a theory is derived in terms of charge shifting amount, which could be used to discuss the electric performance of the graphite-SiO₂ foam.

The localized electric field is constructed when voltages are applied on the two terminals of the sample. This localized electric field would introduce charge carriers as well as current. Charges would be redistributed in space. A charge dynamic process would be introduced at the interface between the metal oxide particle and the graphite particle. A charge q_A in position x_A is supposed to be replaced by another charge q_B in position x_B . An electric force associated with the localized electric field would apply to the charge q_A and change its position. If the charge is shifted with a distance x , then $x=vt$, where t is certain time scale and v is the charge shifting velocity.

Using a simple lattice gas model and assuming that n_A positive charges and n_B negative charges are occupying n lattice sites. The total free energy may be given as

$$f = e\phi(n_A - n_B) + an_A^2 + bn_B^2 + cn_A n_B - k_B T \ln \frac{n!}{(n - n_A - n_B)! n_A! n_B!} \quad (\text{S.1})$$

Here, ϕ is the electrostatic potential; a , b and c are the constants that represent the interactions between the positive charges, the negative charges, and between the positive and negative charges, respectively. The last term is the entropy of the total charge distribution in all available sites. Using Stirling approximation ($\ln n! \approx n \ln n - n$), Eq. (S.1) could be derived as

$$f = e\phi(n_A - n_B) + an_A^2 + bn_B^2 + cn_A n_B - k_B T [\ln n! - (n - n_A - n_B) \ln(n - n_A - n_B) + n - n_A \ln n_A - n_B \ln n_B] \quad (\text{S.2})$$

The derivative of Eq. (S.2) could be taken as

$$\frac{\partial F}{\partial n_A} = e\phi + 2an_A + cn_B - k_B T \ln \frac{n - n_A - n_B}{n_A} \quad (\text{S.3})$$

and

$$\frac{\partial F}{\partial n_B} = -e\phi + 2bn_B + cn_A - k_B T \ln \frac{n - n_A - n_B}{n_B} \quad (\text{S.4})$$

For calculation simplicity, a , b and c are assumed as zero. The free energy would be in its minimum when the whole system is in equilibrium state. Using the condition that its derivative is zero, two equations are derived:

$$\frac{n - n_A - n_B}{n_B} = \exp\left(\frac{-e\phi}{k_B T}\right) \quad (\text{S.5})$$

and,

$$\frac{n - n_A - n_B}{n_A} = \exp\left(\frac{e\phi}{k_B T}\right) \quad (\text{S.6})$$

which could be further derived as

$$\frac{n_A}{n_B} = \exp\left(\frac{-2e\phi}{k_B T}\right) \quad (\text{S.7})$$

If the total volume of the system is V , then the equilibrium charge concentrations at these two positions cc_A and cc_B could be expressed as $cc_A = n_A/V$ and $cc_B = n_B/V$.

Then the ratio of the concentrations is derived as

$$\frac{cc_A}{cc_B} = \exp\left(\frac{-2e\phi(x)}{k_B T}\right) \quad (\text{S.8})$$

Here the electrostatic potential ϕ is depended on the charge shifting distance x . The total charge concentration cc generated is considered as a constant, which is $cc_A + cc_B = cc$.

It is easy to generate

$$cc_A = \frac{cc \exp(\eta)}{1 + \exp(\eta)} \quad (\text{S.9})$$

and

$$cc_B = \frac{cc}{1 + \exp(\eta)} \quad (\text{S.10})$$

Here τ is given by

$$\eta = \frac{2q\phi(x)}{kT} = \frac{2q\phi(vt_0)}{kT} \quad (\text{S.11})$$

Using Poission's law, the charge density and the potential should satisfy

$$\frac{d^2\phi(x)}{dx^2} = \frac{-\rho(x)}{\varepsilon}$$

(S.12)

The charge density could be expressed as .

$$\rho(x) = F(cc_B - cc_A) = \frac{F(\exp(\eta) - 1)cc}{1 + \exp(\eta)} \quad (S.13)$$

Where F is the Faraday constant. It is important to note that the charge q satisfies

$$-q = \int_x^\infty \rho(l)dl \quad (S.14)$$

Combining Eq. (S. 13) and Eq. (S. 14), we can derive,

$$q = -FC[2\ln 2 - 2\ln(e^\eta + 1) + \ln e^\eta] \quad (S.15)$$

which establish the relation of q with η .

Combining Eq. (S.12) and Eq. (S.13), we can generate,

$$\frac{d^2\eta}{dx^2} = \frac{-Fc \exp(\eta) - 1}{\varepsilon \exp(\eta) + 1} \quad (S.16)$$

which could be derived as

$$\frac{d\eta}{dx} = \sqrt{\frac{2Fc}{\varepsilon} [\ln e^\eta - 2\ln(1 + e^\eta)]} \quad (S.17)$$

The electric polarization could be expressed as

$$P = \gamma \frac{\partial q}{\partial w} = \gamma \frac{\partial q}{\partial \eta} \frac{\partial \eta}{\partial w} = \frac{2\gamma QFc}{kT} \left(1 - \frac{2e^\eta}{e^\eta + 1} \right) \quad (S.18)$$

Where $\gamma = LE_0/A$ is the constant that defined by sample length L , sample area A and the electric field E_0 at certain space. Using the well-known electrical polarization expression

$$P = \varepsilon_0(\varepsilon_r - 1)E_0 \approx \varepsilon_0\varepsilon_r E_0 \quad (S.19)$$

and the Mott-Gurney equation,

$$I = (9/8)(A\varepsilon_0\varepsilon_r\mu V_0^2 / L^3) \quad (S.20)$$

the current could be calculated as

$$I = \frac{9\mu V_0^2 Q_0 Fc}{4L^2 kT} \left(1 - \frac{2e^\eta}{e^\eta + 1} \right) \quad (S.21)$$

Where ε_0 is the free space permittivity, ε_r is the relative permittivity, V_0 is the voltage associated with E_0 , μ is permeability, I is the current. If we consider the potential of the point charge and use Eq. (S.11), the potential ϕ could be expressed as

$$\phi(v) = \frac{q}{kT} \frac{Q}{2\pi\varepsilon_0 x} = \frac{q}{kT} \frac{Q}{2\pi\varepsilon_0 vt}$$

(S.22)

Where Q is the charge shifting amount.

Using Eq. (S.11) and Eq. (S.21), we can derive

$$\eta = \frac{q^2 Q}{k^2 T^2 \pi \varepsilon_0 t v} \quad (S.23)$$

Substituting Eq. (S.22) into Eq. (S.20), the current could be expressed as

$$I = \frac{9\mu V_0^2 Q_0 Fc}{4L^2 kT} \left\{ 1 - \frac{2\exp[q^2 Q / (k^2 T^2 \pi \varepsilon_0 t v)]}{\exp[q^2 Q / (k^2 T^2 \pi \varepsilon_0 t v)] + 1} \right\} \quad (S.24)$$

Which has established the relation between the current and the charge shifting amount.

2. The XPS survey of the sample.

Figure S.1 shows the XPS survey of the sample. The peaks at 982 eV, 552 eV, 28.4 eV are caused by the background noise.

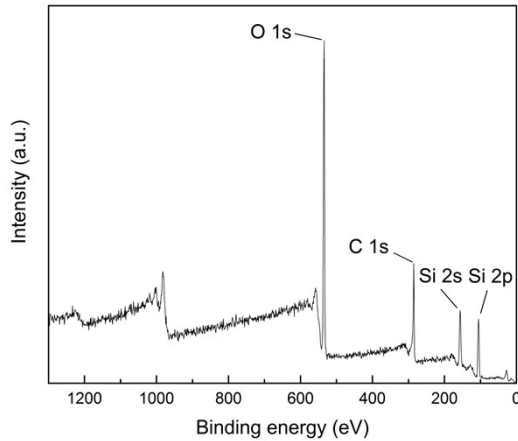


Figure S.1 The XPS survey of the graphite-SiO₂ composite foam.