Supporting Information
Ionic Behavior of Organic-Inorganic Metal Halide Perovskite Based Metal-Oxide-Semiconductor Capacitors

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Model S1:

The value of the total capacitance can be calculated by *Eq. S1−5*, where A is the electrode area (1600×400μm^2), ε is the dielectric constant, which is 3.9 for SiO_2[1], and 11.7 for Si[1], d is the thickness of SiO_2 (150nm), Φ_{fn} is the Fermi potential of Si, N_d is the doping concentration of Si (1×10^{19}cm^{-3}), V_T is the thermal voltage (0.0259eV)[1] and n_i is the intrinsic carrier concentration (1.5×10^{10}cm^{-3})[1]. The value of C_{SiO2} is 148pF by *Eq. S2*, while the value of C_{Simin} is 5.2×10^{-9} F by *Eq. S3-5*. Therefore, C_{si} can be ignored by *Eq. S1*. C_{total} equals to C_{SiO2} (148pF) under low frequency (ε_{PVK} is so large that $1/(C_{it}+C_D)$ can be ignored), and under high frequency (ε_{PVK}=32)[2] is about 110 pF. The 'else' capacitance contains parasitic capacitance and/or capacitance affected by noise or testing error.

$$\frac{1}{C_{\text{total}}} = \frac{1}{C_{Si}} + \frac{1}{C_{Si02}} + \frac{1}{C_{\text{it}} + C_D} + \text{else} \quad \text{(Eq. S1)}$$

$$C_{Si02} = \frac{A\varepsilon_{Si02}}{\text{d}} \quad \text{(Eq. S2)}$$

$$C_{Si\text{min}} = \frac{\varepsilon_{Si} A}{\text{x}_{\text{dt}}} \quad \text{(Eq. S3)}$$

$$\text{x}_{\text{dt}} = \left(\frac{4\varepsilon_{Si}\phi_{fn}}{eN_d}\right)^{0.5} \quad \text{(Eq. S4)}$$

$$\phi_{fn} = V_T \ln\left(\frac{N_d}{ni}\right) \quad \text{(Eq. S5)}$$

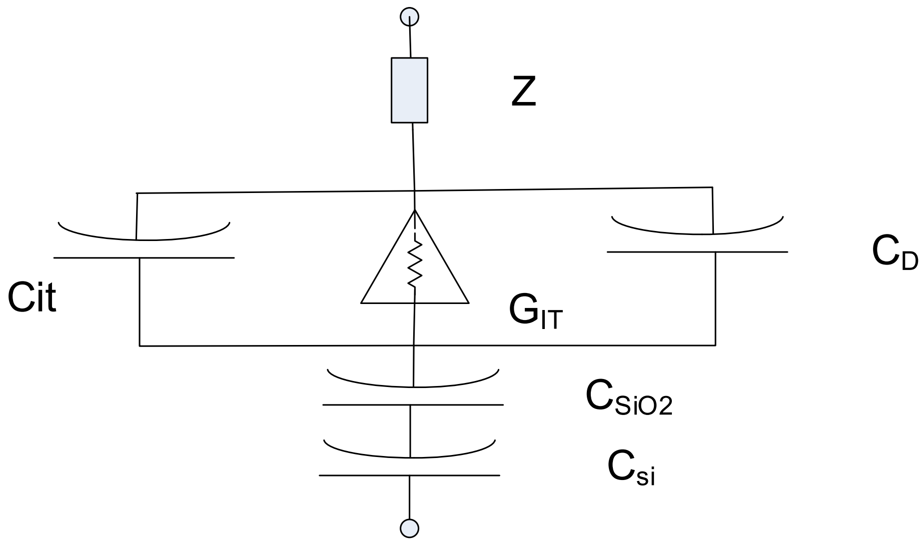

Figure S1. electrical model of Au/$CH_3NH_3PbI_{3-x}Cl_x$ /SiO_2/Si/Al capacitor

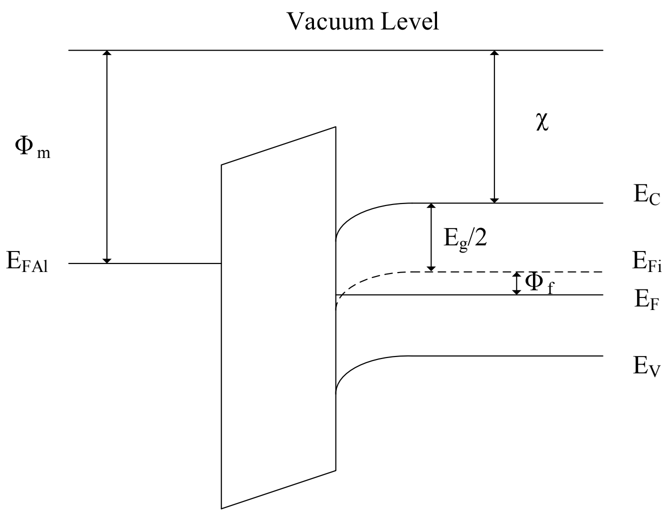

Figure S2. Band diagram of p type Metal-Oxide-Semiconductor capacitors with no gate voltage applied. Φ_m is the work function of the metal, χ is the electron affinity of the semiconductor, E_g is the energy band of PVK, and Φ_f is the Fermi potential.

Fig. S2 gives the band diagram of p type MOS capacitors without gate voltage applied. The metal (Al)-semiconductor (PVK) work function difference can be calculated by Eq. 1. After positive voltage is applied, the depletion width (X_d) will enlarge with the increase of the voltage. Thus the depletion capacitance (C_D) is reduced, and the total capacitance (C_{total}) is reduced according to Eq. S1. In this way, the minimum total capacitance appears when the depletion capacitance reaches its minimum value, which is the maximum of the depletion width (X_{dt}). Then the voltage when the capacitance reaches its minimum (V_{cmin}) is the sum of gate oxide voltage (eBX_{dt}/C_{ox}), the metal (Al)-semiconductor (PVK) work function difference (Φ_{ms}), and the surface potential ($2\Phi_f$).

References:

(1) D. A. Neaman. Semiconductor physics and devices, Chicago: Irwin, 1992.

(2) H. S. Jung and N. G. Park, *small* 2015, **11**, 10-25.