

Supporting Information

Frequency switchable correlated transports in perovskite rare-earth nickelates

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Section A. Supplementary method:

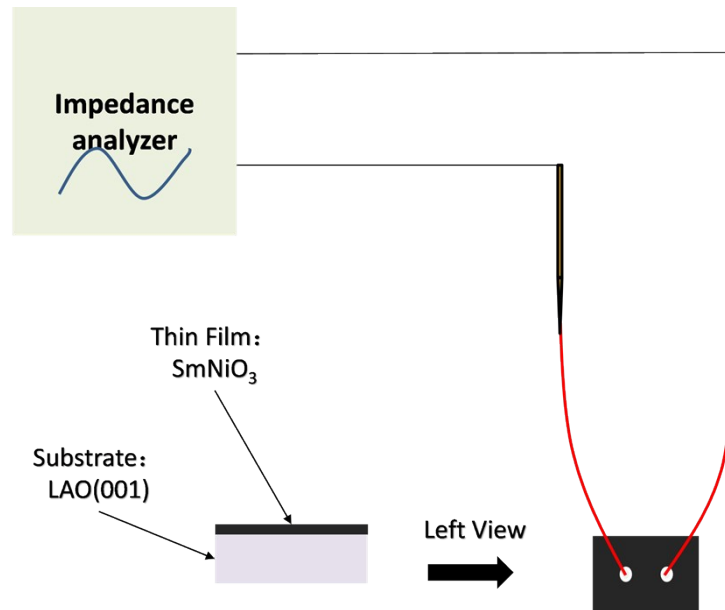


Figure S1. Schematic illustration for the impedance measurement. Since the ReNiO_3 will be further used as a thermistor, a similar two point contact was used for characterization.

Section B. Additional Results:

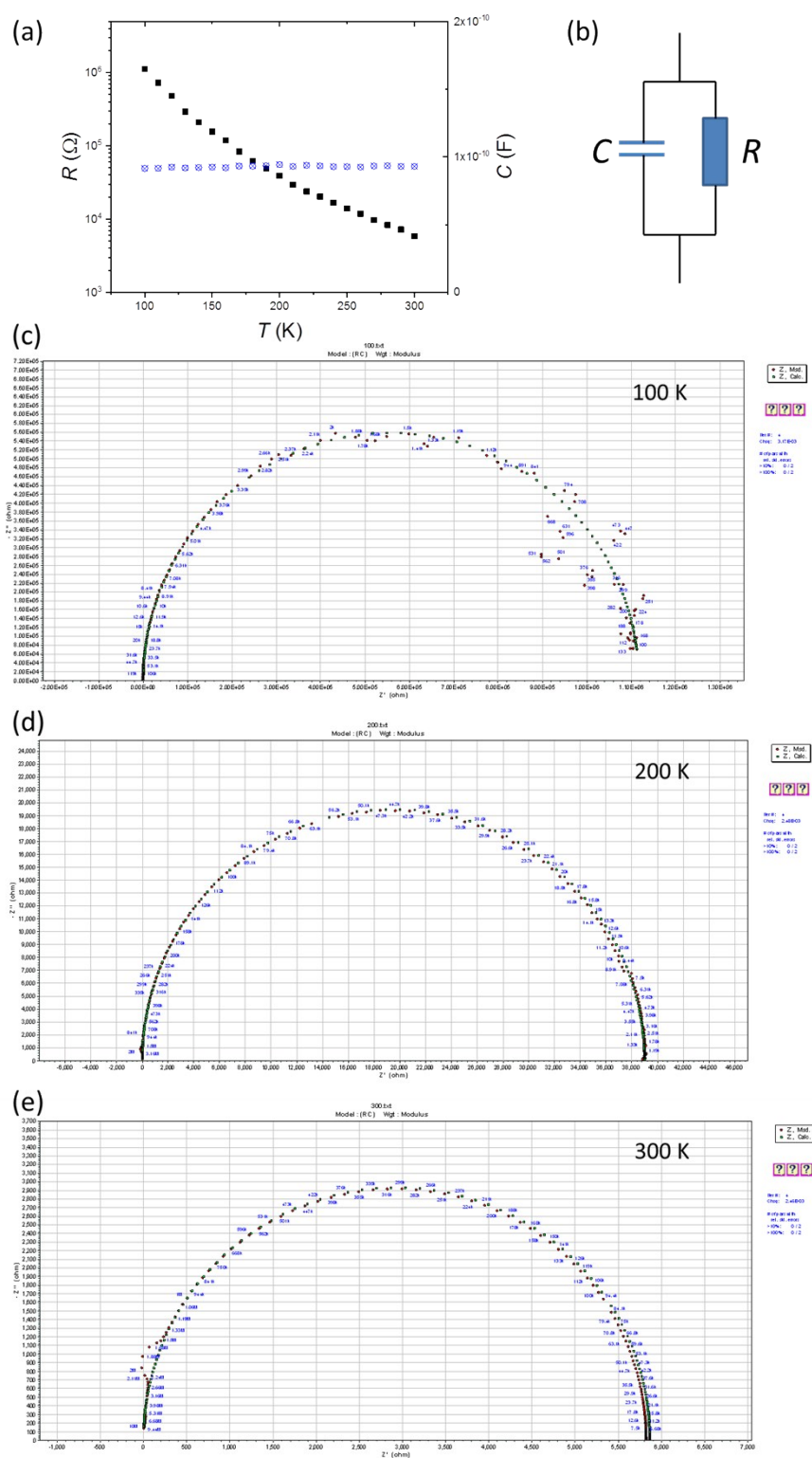


Figure S2. (a) Temperature dependence of the fitted resistance and capacitance for the impedance spectrums of $\text{SmNiO}_3/\text{LaAlO}_3$ measured at various temperatures in Figure 2a and 2b. (b) Illustrating the equivalent circuit used for fitting. (c) Representative core-core curve and fittings.

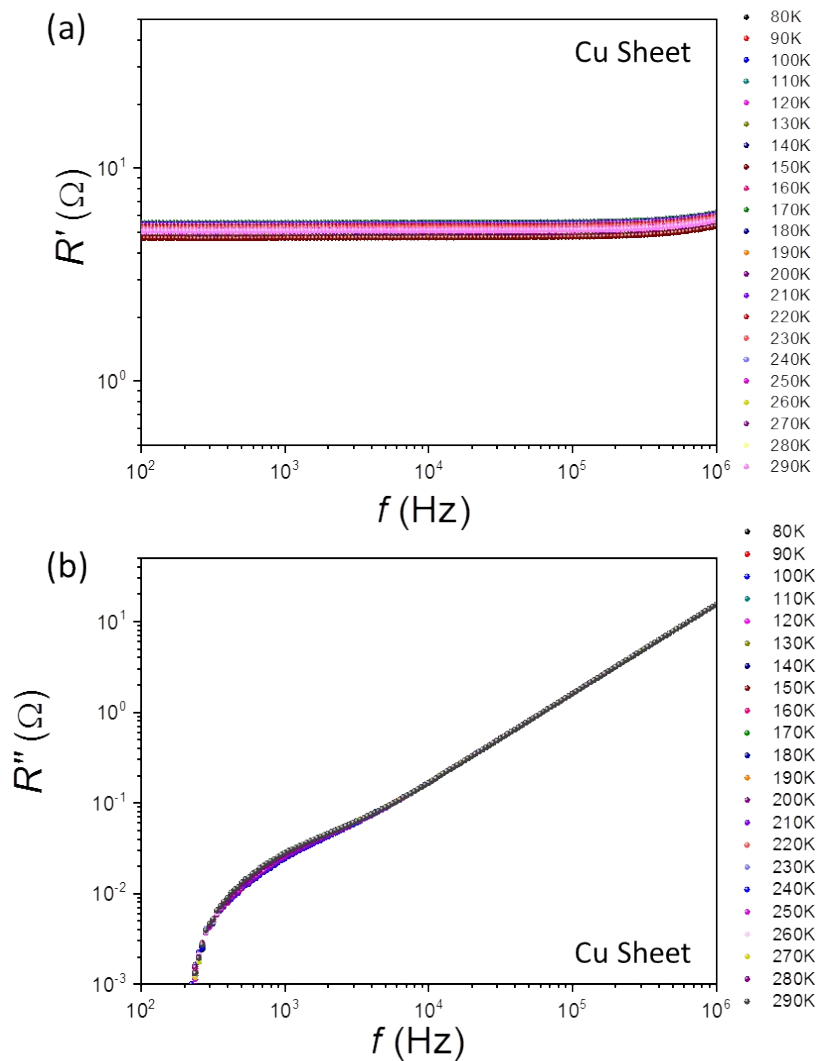


Figure S3. The impedance ($R'+iR''$) measured as a function of AC-frequency for a piece of copper sheet at various temperatures: **(a)** the R' - f_{AC} curves and **(b)** the R'' - f_{AC} curves. For all the investigated temperatures, the R' shows a plateau magnitude similar to each other, which is a typical character for conventional metals. Owing to the high carrier concentration and low Coulomb viscosity within metals, the contribution by lattice polarization is completely shielded by the electron free carriers. As a result, an electrical transportation is similar to direct current situation is expected, while the increase in R'' at small magnitude can be explained by the slight weakening in the shielding of lattice polarizations when elevating the AC-frequency.

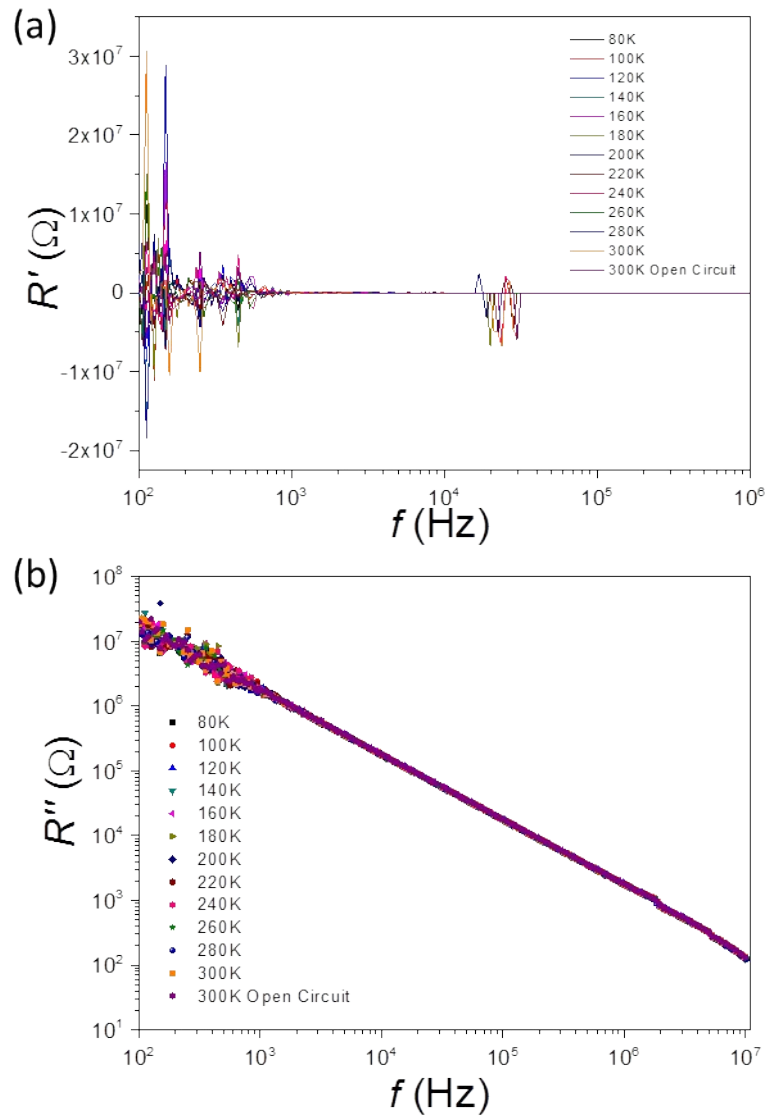


Figure S4. The impedance ($R' + iR''$) measured as a function of AC-frequency for the LaAlO₃ obtained by polishing off the film material from SmNiO₃/LaAlO₃ substrate at various temperatures: (a) the R' - f_{AC} curves and (b) the R'' - f_{AC} curves. The resistivity (R') at low AC-frequencies of LaAlO₃ substrate is too large that beyond the detectable range (no reliable signal is detected), and the conduction is dominated by AC mode. The reducing tendency in R'' with the AC-frequency indicates the constant magnitude of electronic capacitance.

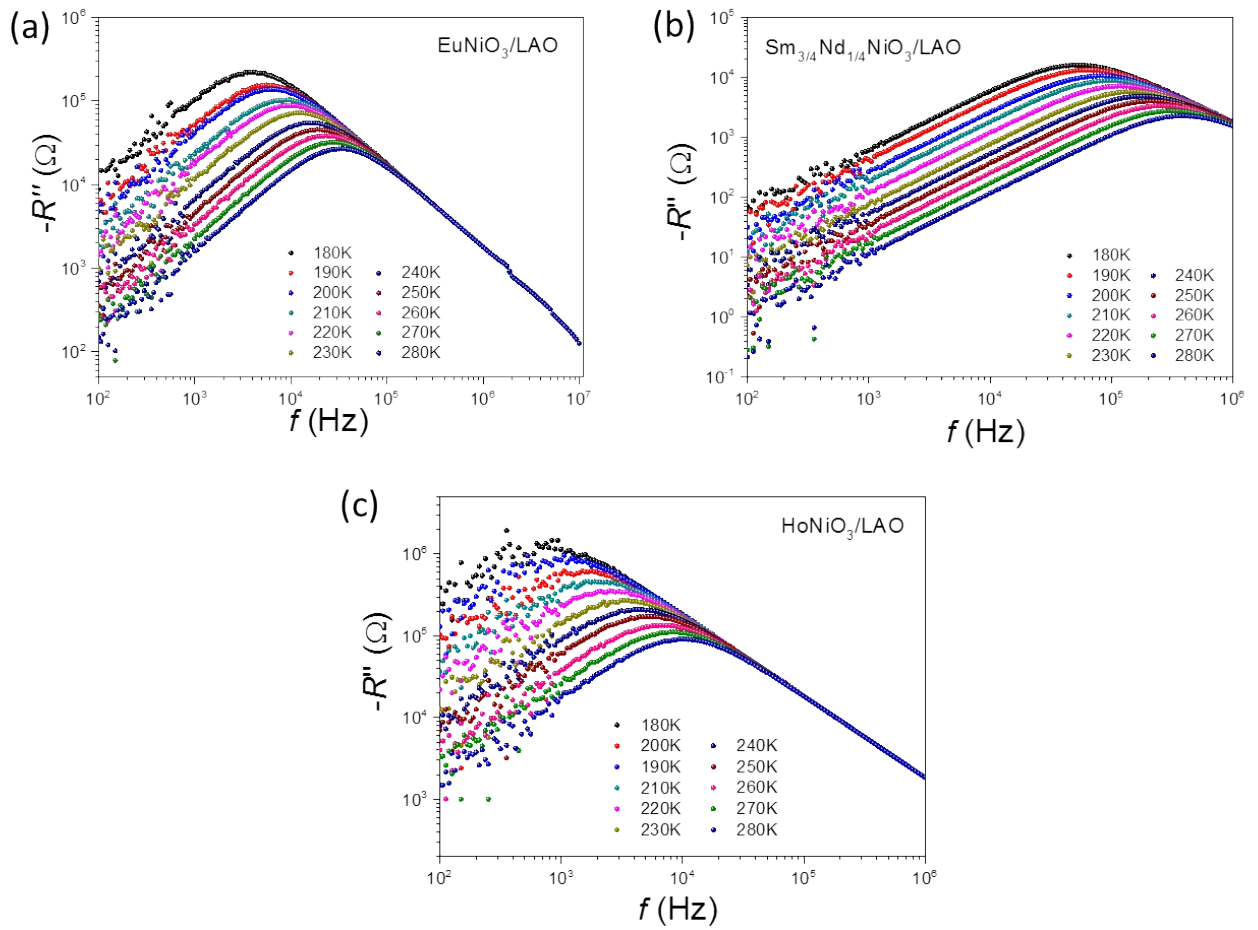


Figure S5. The R'' - f tendencies measured at various temperatures for (a) $\text{EuNiO}_3/\text{LaAlO}_3$, (b) $\text{Sm}_{3/4}\text{Nd}_{1/4}\text{NiO}_3/\text{LaAlO}_3$ and (c) $\text{HoNiO}_3/\text{LaAlO}_3$, respectively, while their respective R'' - T tendencies are shown in Figure 3a. It can be seen that the maximum frequency in R'' is similar to the critical frequency to trigger the abrupt reduction in R' at each temperature.

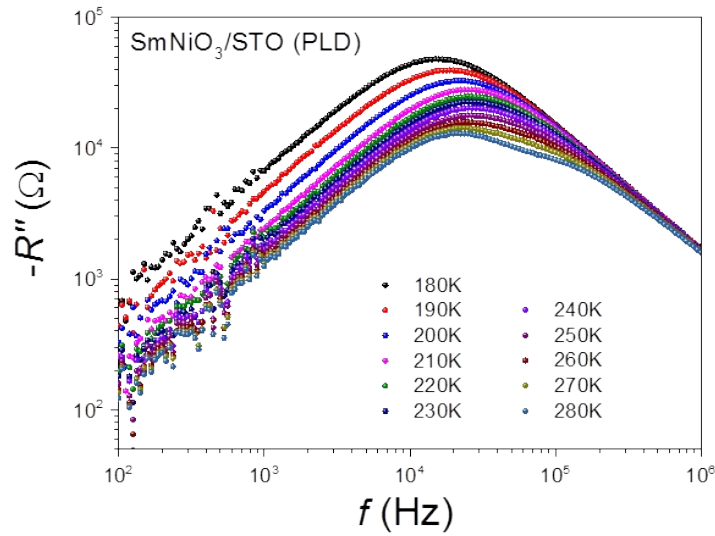


Figure S6. The R'' - f tendencies measured at various temperatures for the biaxial tensile distorted $\text{SmNiO}_3/\text{SrTiO}_3$, while its respective R'' - T tendencies are shown in Figure 3c. It can be seen that the maximum frequency in R'' is similar to the critical frequency to trigger the abrupt reduction in R' at each temperature.

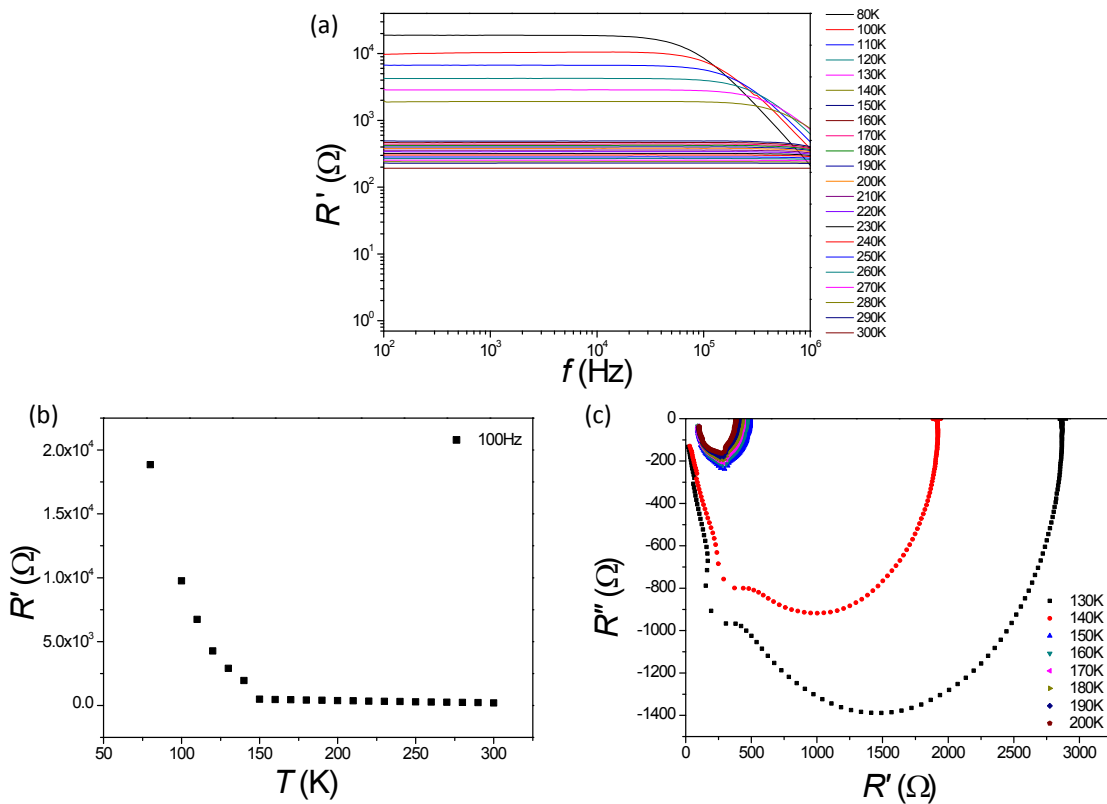


Figure S7. (a) The R' - f tendencies, (b) $R'_{(100\text{ Hz})}$ - T and (c) R' - R'' tendencies measured for $\text{NdNiO}_3/\text{LaAlO}_3$ across its metal to insulator transition point.

Section C. Additional Discussions:

To obtain the temperature dependence of the Coulomb viscosity $\eta(T)$, we utilize the Drude

model to describe the conductivity (σ) of SmNiO₃ as: $\sigma = \frac{nq^2\tau}{m^*}$, where n , q , m^* represent for the concentration, charge and effective mass of the carrier, while τ is the life time between the carrier scatterings. Herein, we consider the temperature dependence of n , as

$n_{(T)} = n_0 \exp\left(\frac{-E_g}{k_B T}\right)$, where n_0 is a constant initial carrier concentration and E_g represents for the energy band gap, while $m^*_{(T)}$, as $m^*_{(T)} = \eta(T) m^*_0$, while the magnitude of τ is considered to be saturated at a small number based on the previous report about the bad metal transportation behavior for SmNiO₃. Therefore, the temperature dependent conductivity can be written as the following equation:

$$\sigma_{(T)} = \frac{n_0 \exp\left(\frac{-E_g(T)}{k_B T}\right) q^2 \tau}{\eta(T) m^*_0} ; \quad (1)$$

From the inset shown in Figure 2f, we already calculated the activation energy (E_a) from the temperature dependence of resistance measured for ReNiO₃, as $R_{(T)} = R_0 \exp[E_a(k_B T)^{-1}]$. Based on this result, we further fitted the temperature dependence of E_a from the $\ln(\sigma_{100\text{Hz}}) - 1000/T$ tendency, e.g. as: $E_{a(T)} = E_0 T^A$. Therefore, we get the following two relationships:

$$E_{a(T)} = \frac{d \ln[\sigma_T]}{d(1000/T)} ; \quad (2)$$

$$\beta = \frac{dE_a}{dT} ; \quad (3)$$

Putting (1) in (2) to obtain the expression of E_a with respect to T , and further relating this obtained expression with (3), we are able to get the analytical expression of $\eta(T) = T^{1000\beta} = T^A$. When considering a non-temperature dependent energy band gap, we can obtain $A=4$.

For the situation when there is temperature dependences in the electronic energy band gap, we can further obtain the equation from the following group functions:

$$\left\{ \begin{array}{l} \ln \sigma(T) = \ln n_o e^{2\tau} + \frac{E_g(T)}{k_B T} - \ln [m^*(T)] \quad (4) \\ E_a(T) = \frac{d \ln \sigma(T)}{d \frac{1000}{T}} = \left(\frac{T}{1000 k_B} \right) \frac{dE_g(T)}{dT} - \frac{E_g(T)}{1000 k_B} - \frac{d \ln [m^*(T)]}{d \frac{1000}{T}} \quad (5) \\ \frac{dE_a(T)}{dT} = \beta \quad (3) \end{array} \right.$$

Putting the expression of $E_g(T)$ From (3)-(5), we get:

$$\frac{dE_a(T)}{dT} = \frac{E_g''(T) \cdot T}{1000 k_B} + 2T \cdot \frac{d \ln [m^*(T)]}{1000 dT} + T^2 \cdot \frac{d^2 \ln [m^*(T)]}{1000 dT^2} = \beta \quad (6)$$

From (6), we let with respect to the case that dE_a/dT is not varying with temperature:

$$-\frac{E_g''(T) \cdot T}{k_B} + 2T \cdot \frac{d \ln [m^*(T)]}{dT} + T^2 \cdot \frac{d^2 \ln [m^*(T)]}{dT^2} = A \quad (7)$$

From the inset shown in Figure 2f, E_a exhibits a linear temperature dependence, and thereby A is a constant. Thus, the following two possible solutions are supposed to fit the present situation for equation (7):

$$E_g''(T) = 0 \text{ or } \frac{C}{T}$$

For the first case when $E_g''(T) = 0$, we let: $E_g(T) = kx + b$, where k and b are constants.

The previously obtained $m^*(T) = T^A$ relationship will not be mathematically influenced, no

matter whether $k > 0$ or $k < 0$, since $E_g''(T) \equiv 0$.

For the second case when $E_g''(T) = \frac{C}{T}$, we can get: $E_g(T) = C_1 [T \ln T - T + C_2]$, where C_1

and C_2 are constants. Then, $E_g''(T) = \frac{C_1}{T}$ and $m^*(T) = T^{C_2}$. Put these equations back to equation

(6), we can obtain: $C_2 = A + \frac{C_1}{k_B}$. Therefore, when $C_1 > 0$, we get an increasing temperature dependence for $E_g(T)$ that increases the power in the positive temperature dependence of $m^*(T)$, while when $C_1 < 0$ results in an reducing temperature dependence in $E_g(T)$ that reduces

the power in the positive temperature dependence of $m^*(T)$. Nevertheless, it is worthy to note that within the investigated range of temperature, e.g. 50-300 K, the expression of $f(T) =$

$T \ln T - T$ exhibits a monotonic increasing tendency with T that is very similar to $f(T) = 5T - 146.8$. Therefore, the second case can be approximately considered as a special case that is included within the first case.