Supplementary Material

Nanophotonic design of perovskite/silicon tandem solar cells

Mohammad I. Hossain[a], W. Qarony[a], V. Jovanov[b], Yuen H. Tsang[a], D. Knipp[b,c,*]

a.) Department of Applied Physics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

b.) Research Center for Functional Materials and Nanomolecular Science, Jacobs University Bremen, 28759 Bremen, Germany

c.) Geballe Laboratory for Advanced Materials, Department of Materials Science and Engineering, Stanford University, Stanford, CA 94305, USA

*.) Corresponding author: E-mail: dknipp@stanford.edu

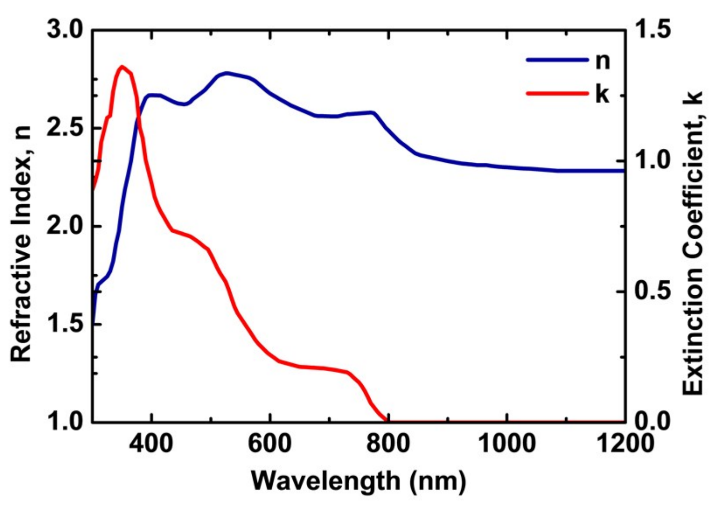

Figure S1. Refractive index (n) and extinction coefficient (k) of $CH_3NH_3PbI_3$ perovskite adapted from Löper et.al [S1].

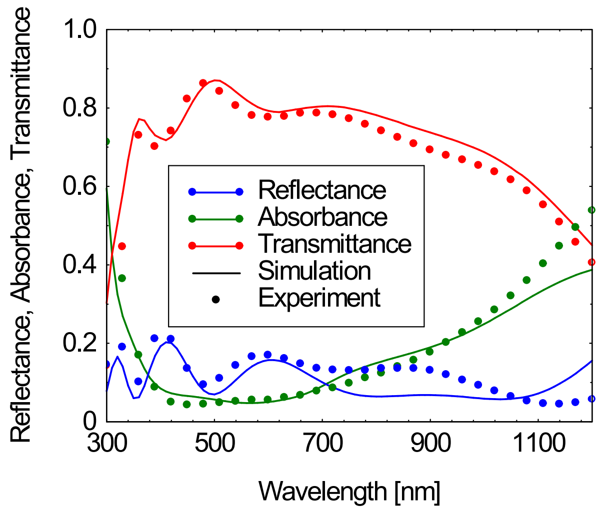

Figure S2. Measured and simulated reflectance, transmittance, and absorbance of a ITO film with a thickness of 240 nm prepared on a glass substrate. A Lorentz and an extended Drude Model was used to describe the complex refractive index of the ITO film. Parameters used for the calculation of the reflectance, transmittance and absorbance are given in Table S1. The measured data is adapted from Ref. S2.

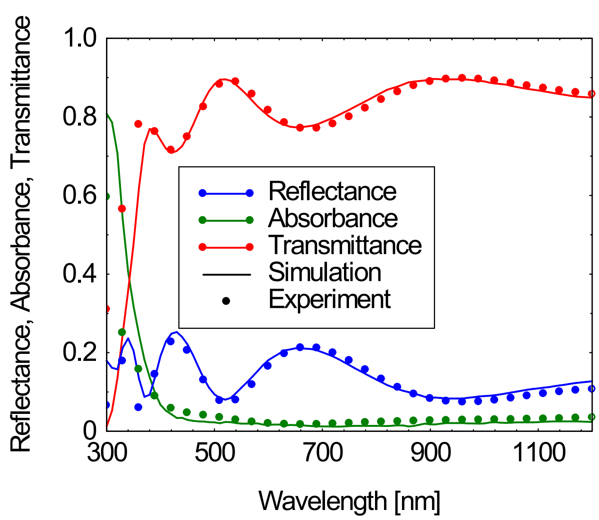

Figure S3. Measured and simulated reflectance, transmittance, and absorbance of a IOH film with a thickness of 240 nm prepared on a glass substrate. A Lorentz and an extended Drude Model was used to describe the complex refractive index of the ITO film. Parameters used for the calculation of the reflectance, transmittance and absorbance are given in Table S1. The measured data is adapted from Ref. S2.

The complex refractive index of the metal oxide films is required as input parameter for the optical simulation.

$$n + ik = \sqrt{\varepsilon(\omega)} \tag{S1}$$

The dielectric function is determined by using a Drude Lorentz model. The dielectric function is given by

$$\varepsilon(\omega) = \varepsilon_L(\omega) + \varepsilon_D(\omega), \tag{S2}$$

where $\varepsilon_D(\omega)$ and $\varepsilon_L(\omega)$ are the Lorentz and Drude contributions to the dielectric function. The Lorentz dielectic function is given by

$$\varepsilon_L(\omega) = \frac{\Omega_N^2}{\Omega_0^2 - \omega^2 - i\Omega_\Gamma \omega}, \tag{S3}$$

where Ω_N, Ω_0 and Ω_Γ are the plasma frequency, resonant frequency and damping frequency. The Drude dielectric function is given by

$$\varepsilon_D(\omega) = \varepsilon_\infty - \frac{\omega_N^2}{\omega^2 + i\Gamma\omega}, \tag{S4}$$

The Drude dielectric function is given by where ε_∞ , ω_N and Γ are the high frequency dielectric function, the unscreened plasma frequency and the damping frequency. Equation S1 to S4 were used to describe the complex refractive index of the zinc oxide film [S3]. To describe the ITO and IOH film the Drude model was extended by the following expression for the frequency dependent damping frequency,

$$\Gamma(\omega) = \Gamma_L - \frac{\Gamma_L - \Gamma_H}{\pi} \times \left[\arctan\left(\frac{\omega - \omega_{cross}}{\omega_{width}} \right) + \frac{\pi}{2} \right], \tag{S5}$$

where Γ_{min} and Γ_{max} are the minimal and maximal of the damping frequency, while ω_{cross} and ω_{width} are the crossover frequency and the width of the transition region [S4-S6]. The extented Drude model accounts for the frequency dependent mobility, where the conductive for $\omega \rightarrow 0$ corresponds to the DC conductivity. The measured reflectance, transmittance and absorbance in Fig. S2 and S3 was fitted by using equation S1 to S5. The parameters used to fit the experimental data are summarized in Tab. S1.

Based on the extracted plasma frequency the doping concentration was determined by

$$N_{opt} = \frac{\omega_N^2 \varepsilon_0 m_e}{q^2}, \qquad \text{(S6)}$$

where ε_0, m_e, and q are the vacuum permittivity, mass of an electron and elementary charge. Furthermore, the DC conductivity (σ_{DC}) and resistivity (ρ_{DC}) of the metal oxide films can be determined by

$$\sigma_{DC} = \frac{1}{\rho_{DC}} = \frac{\varepsilon_0 \omega_N^2}{\Gamma}. \qquad \text{(S7)}$$

Based on the optical determined electrical parameters of the films the charge carrier mobility can be calculated by

$$\mu_{opt} \approx \frac{\sigma_{DC}}{q N_{opt}} = \frac{q}{\Gamma m_e}. \qquad \text{(S8)}$$

	Material		
Extracted parameters	**ITO**	**IOH**	**ZnO**
N_{opt}:= Doping concentration [1/cm^3]	10×10^{20}	3.9×10^{20}	2.5×10^{19}
μ_{opt}:= Carrier mobility [cm^2/V/s]	22.5	66	35
ρ_{opt}:= Electrical Resistivity [Ωcm]	2.3×10^{-4}	2.4×10^{-4}	7×10^{-3}

Tab. S1: Summary of Drude, extended Drude and Lorentz dielectric model. Extracted doping concentration and charge carrier mobility and experimental data from literature [S1,S2].

References:

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[S3] J. Steinhauser, PhD Thesis University Neuchatel, 2008.

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