Supporting Information

Rapid Thickness Reading of $CH_3NH_3PbI_3$ Nanowire This Films from Color Maps

Massimo Spina, Claudio Grimaldi, Bálint Náfrádi, László Forró, and Endre Horváth

Laboratory of Physics of Complex Matter (LPMC), Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Calculation of reflectance

To calculate the reflectance spectrum of $MAPbI_3$/dielectric/Si multilayers as function of the light wavelength λ, we first evaluate for a given angle θ of the incident light the reflectance intensity $R(\lambda)$. As schematically shown in Fig. S1, the $MAPbI_3$ layer has thickness d_1 and index of refraction $n_1 - ik_1$; the dielectric (e.g., SiO_2 or TiO_2) layer has thickness d_2 and index of refraction $n_2 - ik_2$; the Si semi-infinite substrate has index of refraction $n_3 - ik_3$. The reflectance intensity is [1]:

$$R(\lambda) = \left| \frac{r_1 + r_2 e^{-2i\delta_1} + r_3 e^{-2i(\delta_1+\delta_2)} + r_1 r_2 r_3 e^{-2i\delta_2}}{1 + r_1 r_2 e^{-2i\delta_1} + r_1 r_3 e^{-2i(\delta_1+\delta_2)} + r_2 r_3 e^{-2i\delta_2}} \right|^2 \tag{1}$$

where r_1, r_2, and r_3 are the amplitudes of the light reflected at the interfaces between, respectively, air and $MAPbI_3$, $MAPbI_3$ and dielectric, and dielectric and silicon. The phase changes across $MAPbI_3$ and dielectric are given respectively by:

$$\begin{aligned} \delta_1 &= (2\pi d_1 / \lambda)(n_1 - ik_1)\cos\theta_1, \\ \delta_2 &= (2\pi d_2 / \lambda)(n_2 - ik_2)\cos\theta_2, \end{aligned} \tag{2}$$

where θ_1 and θ_2 are the propagation angles for $MAPbI_3$ and SiO_2 (see fig. S1). Using Snell's law we express the propagation angles In terms of the incident angle θ: $\sin\theta_j = \sin\theta / (n_j - ik_j)$, with $j = 1,2,3$. We can thus rewrite the phase changes as:

$$\begin{aligned} \delta_1 &= (2\pi d_1 / \lambda)(u_1 - iv_1), \\ \delta_2 &= (2\pi d_2 / \lambda)(u_2 - iv_2), \end{aligned} \tag{3}$$

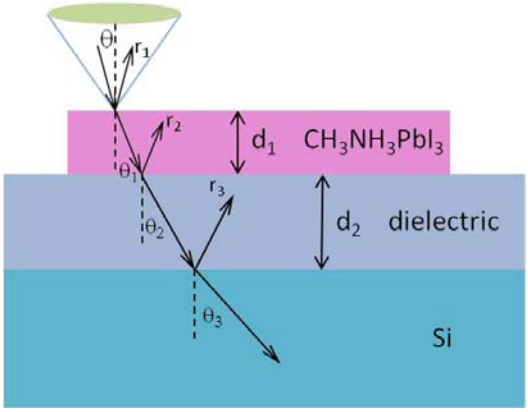

Fig. S1. Schematic representation of a $CH_3NH_3PbI_3$/dielectric/Si multilayer system.

where for $j = 1,2,3$:

$$u_j = \sqrt{\frac{e_j - \sin^2\theta + \sqrt{\left(e_j - \sin^2\theta\right)^2 + f_j^2}}{2}}, \quad v_j = \sqrt{\frac{\sin^2\theta - e_j + \sqrt{\left(e_j - \sin^2\theta\right)^2 + f_j^2}}{2}}, \tag{4}$$
$$e_j = n_j^2 - k_j^2, \qquad f_j = 2n_j k_j.$$

Using Eq. (4), the s-polarized and p-polarized reflection amplitudes are written as [1]:

$$r_{1s} = \frac{\cos\theta - (u_1 - iv_1)}{\cos\theta + (u_1 - iv_1)}, \quad r_{2s} = \frac{u_1 - iv_1 - (u_2 - iv_2)}{u_1 - iv_1 + (u_2 - iv_2)}, \quad r_{3s} = \frac{u_2 - iv_2 - (u_3 - iv_3)}{u_2 - iv_2 + (u_3 - iv_3)}, \tag{5}$$

$$\begin{aligned} r_{1p} &= \frac{(n_1 - ik_1)^2\cos\theta - (u_1 - iv_1)}{(n_1 - ik_1)^2\cos\theta + (u_1 - iv_1)}, \\ r_{2p} &= \frac{(u_1 - iv_1)^2(n_2 - ik_2)^2 - (u_2 - iv_2)(n_1 - ik_1)^2}{(u_1 - iv_1)^2(n_2 - ik_2)^2 + (u_2 - iv_2)(n_1 - ik_1)^2}, \\ r_{3p} &= \frac{(u_2 - iv_2)(n_3 - ik_3)^2 - (u_3 - iv_3)^2(n_2 - ik_2)}{(u_2 - iv_2)(n_3 - ik_3)^2 + (u_3 - iv_3)^2(n_2 - ik_2)}. \end{aligned} \tag{6}$$

We average the reflection intensity (1) over the two polarizations and, to take into account the finite numerical aperture (NA) of the microscope, we perform a numerical average between $\theta = 0$ and $\theta = \theta_0 = \sin^{-1}(NA)$.

In calculating the reflectance intensity, we take the real (n_1) and imaginary (k_1) parts of the refractive coefficient of $MAPbI_3$ measured in Ref.[2], shown in fig. S2a. In figs. S2b and S2c we report the refractive indexes of SiO_2 and Si used in the calculations.

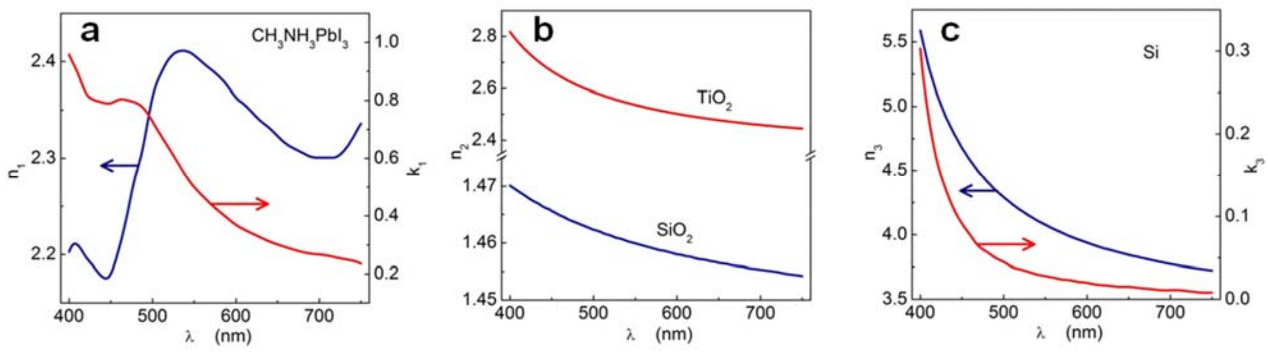

Fig. S2: Refractive coefficients of $MAPbI_3$ [2] (a), SiO_2 and TiO_2 (b), and Si (c).

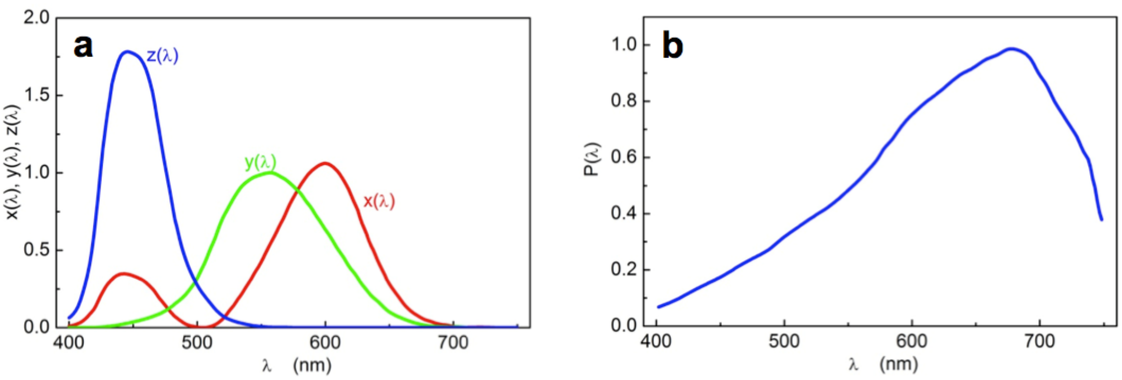

Fig. S3: CIE color matching functions (a) and renormalized power spectrum of an halogen lamp (b)

Conversion to RGB components

To calculate the color spectrum of $MAPbI_3$/dielectric/Si multilayers, we must convert the reflectance intensity into red (R), green (G), and blue (B) parameters, as described in Ref.[3]. We first calculate the tristimulus components:

$$
\begin{aligned}
X &= \int d\lambda P(\lambda)R(\lambda)x(\lambda),\\
Y &= \int d\lambda P(\lambda)R(\lambda)y(\lambda),\\
Z &= \int d\lambda P(\lambda)R(\lambda)z(\lambda),
\end{aligned} \tag{7}
$$

where $x(\lambda)$, $y(\lambda)$, and $z(\lambda)$ are the CIE color-matching functions shown in fig. S3a and $P(\lambda)$ is the power spectrum of the source light. Optical micrographs were taken using an halogen lamp of color temperature 3200 K, with approximate (normalized) power spectrum given in fig. S3b.

The RGB parameters are obtained from

$$
\begin{bmatrix} R \\ G \\ B \end{bmatrix} = M^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \tag{8}
$$

where the transformation matrix is defined as [4]:

$$
M = \begin{bmatrix} S_R X_R & S_G X_G & S_B X_B \\ S_R Y_R & S_G Y_G & S_B Y_B \\ S_R Z_R & S_G Z_G & S_B Z_B \end{bmatrix}. \tag{9}
$$

The elements of the transformation matrix are given by $X_i = x_i / y_i$, $Y_i = 1$, and $Z_i = (1 - x_i - y_i) / y_i$, with $i = R,G,B$, where $(x_R = 0.64, y_R = 0.33)$, $(x_G = 0.3, y_G = 0.6)$, and $(x_B = 0.15, y_B = 0.06)$ are the chromaticity coordinates of an RGB system [3,4]. Furthermore:

$$
\begin{bmatrix} S_R \\ S_G \\ S_B \end{bmatrix} = \begin{bmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{bmatrix} \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix}, \tag{10}
$$

where X_W, Y_W, and Z_W, obtained by setting $R(\lambda) = 1$ in eq. (7), are the tristimulus components of the reference white of the light source. Finally, the RGB parameters are scaled according to ($i = R,G,B$):

$$
i = \begin{cases} 12.92 i & i \le 0.00313 \\ 1.055 i^{1/2.4} - 0.055 & i \ge 0.00313 \end{cases}. \tag{11}
$$

The so-obtained RGB parameters are then multiplied by 255 to convert them to a color scheme ranging from 0 to 255.

References

[1] I. Jung et al., Simple approach for high-contrast optical imaging and characterization of graphene-based nanosheets, Nanolett., 2007, 7, 3569-75.

[2] G. Xing et al., Low-temperature solution-processed wavelength-tunable perovskites for lasing, Nature Mater., 2014, 13, 476-80.

[3] J. Henrie, S. Kellis, S. M. Schultz, and A. Hawkins, Electronic color charts for dielectric films on silicon, Opt. Express, 2004, 12, 1464-9.

[4] B. 4, http://www.bruce4.com.