Measurement of Mobility-Lifetime products in $MAPbI_3$ films

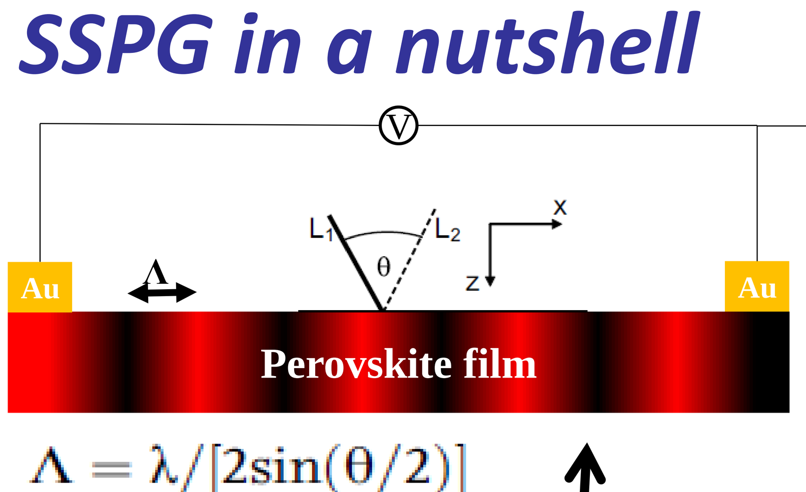
Igal Levine[1], Satyajit Gupta[1], Thomas M. Brenner[1], Gary Hodes[1], Doron Azulay[2], Oded Millo[2], Isaac Balberg[2], and David Cahen[1]

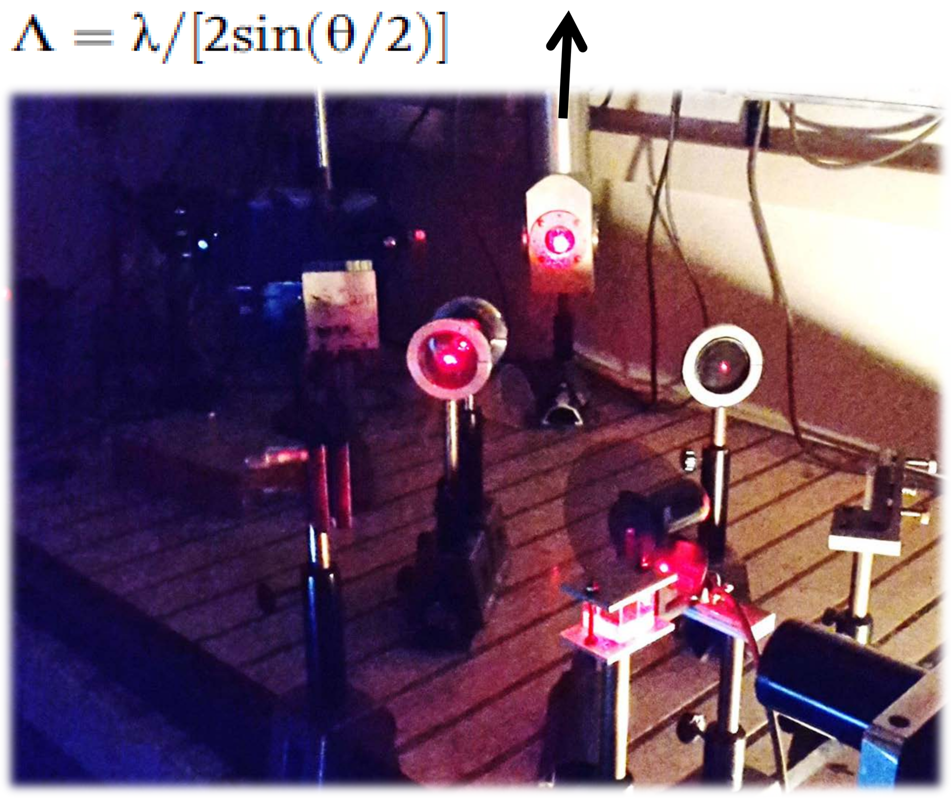
[1]*Dept. of Materials & Interfaces, Weizmann Inst. of Science, Rehovot 76100, Israel*
[2]*The Racah Institute, The Hebrew University, Jerusalem 91904, Israel*

Abstract

In this work we analyze the mobility-lifetime products and their light dependencies in $MAPbI_3$ films, prepared by the one-step method. Photoconductivity measurements are used to determine the mobility-lifetime product of the majority carriers, while the Steady-State Photocarrier-Grating (SSPG) technique is used to determine the diffusion length and thus the mobility-lifetime product of the minority carriers. SSPG is based on the presence of a spatial sinusoidal modulation in the photogeneration rate G of electronic charge carriers, which induces a so-called photocarrier grating. We find that the obtained ambipolar diffusion lengths of the $MAPbI_3$ films are highly dependent on the route used for preparing the films. For films prepared using lead acetate we find that the diffusion length is 300-400 nm, without significant dependence on the light intensity used, while for films prepared using lead chloride precursor, the diffusion length is in the range or greater than 700 nm.

SSPG in a nutshell



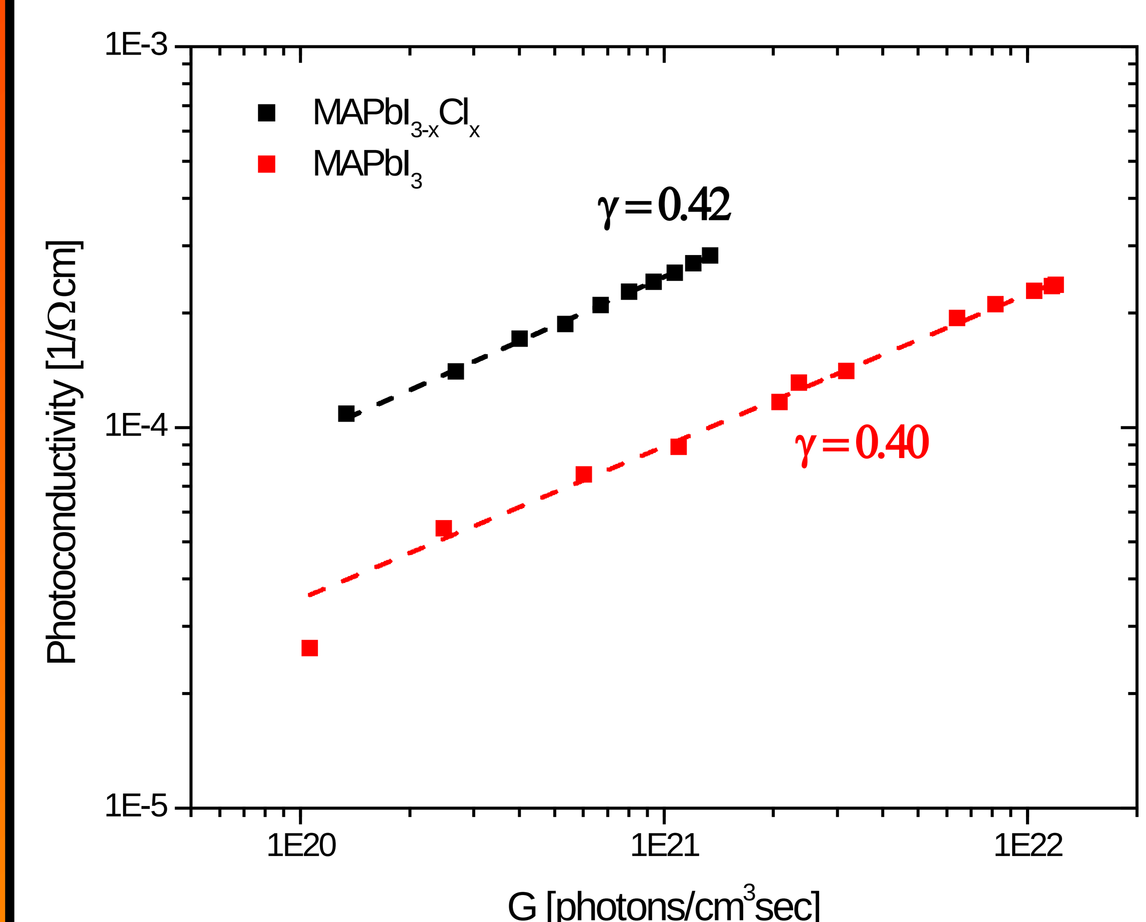


- Two coherent/incoherent laser beams hit the sample and create an interference pattern.
- By changing the polarization of one of the beams, we can measure the photoconductivity with (=*coherent*) and without (=*incoherent*) the interference pattern.
- The ratio between the change in photoconductivity in the two conditions is defined as **β**.
- Measurements using different grating periods, **Λ**, yield the diffusion length of the minority carriers, L_D, using ***Balberg plot:***

$$\sqrt{\frac{2}{1-\beta}} = \frac{1}{\sqrt{Z}}\left(\frac{1}{\Lambda^2}\right)(2\pi L_D)^2 + \frac{1}{\sqrt{Z}} \rightarrow L_D = \frac{1}{2\pi}\sqrt{\frac{slope}{intercept}}$$

Lifetime-Mobility product of the Majority Carriers

$$\sigma_{ph} \propto G^{\delta}$$



$$\sigma_{ph} = qG\left[(\mu\tau)_{maj} + (\mu\tau)_{min}\right]$$

$$\frac{\sigma_{ph}}{qG} > 1.1\times10^{-7}\ \frac{cm^2}{V}$$

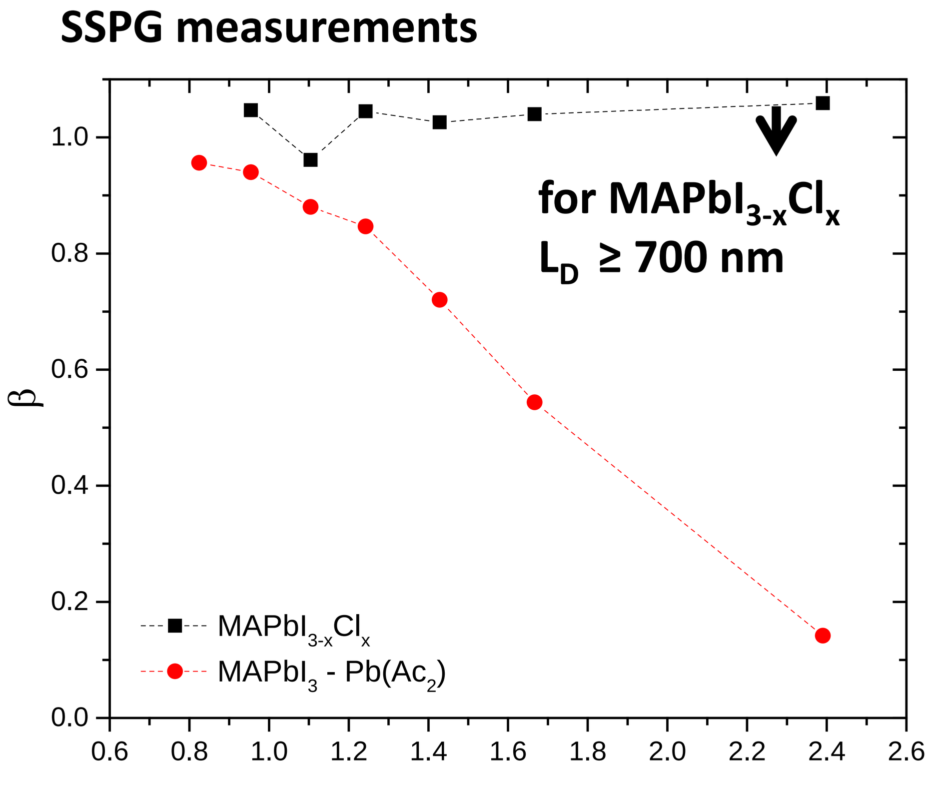
$$\downarrow$$

$$(\mu\tau)_{maj} > 8.1\times10^{-8}\ \frac{cm^2}{V}$$

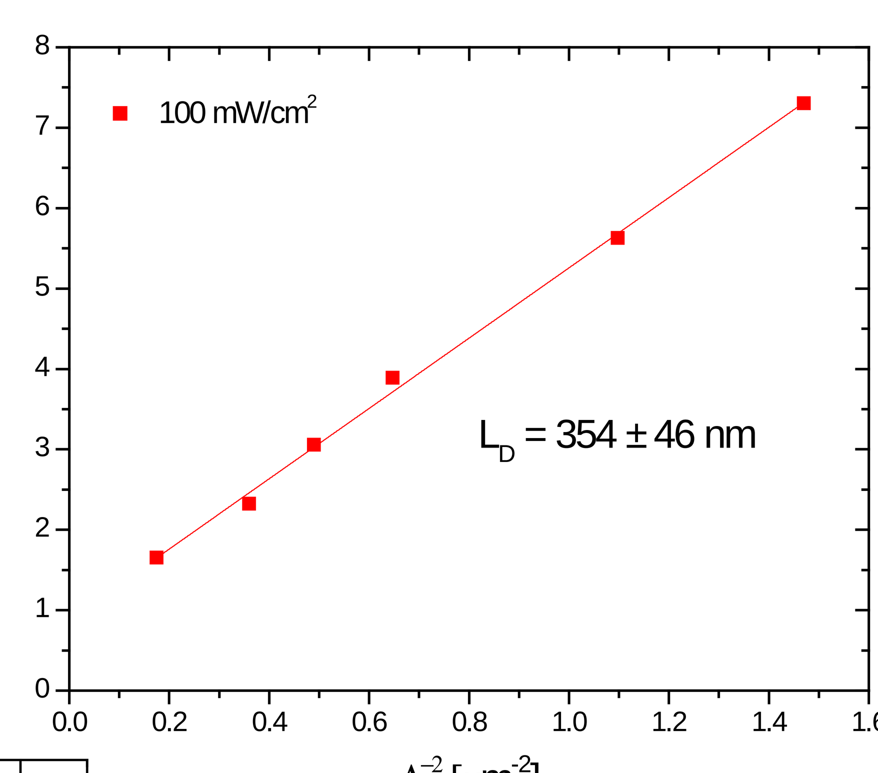
***$(\mu\tau)_{maj}$ will probably be lower due to actual lower G**

Mobility-Lifetime product of the Minority Carriers

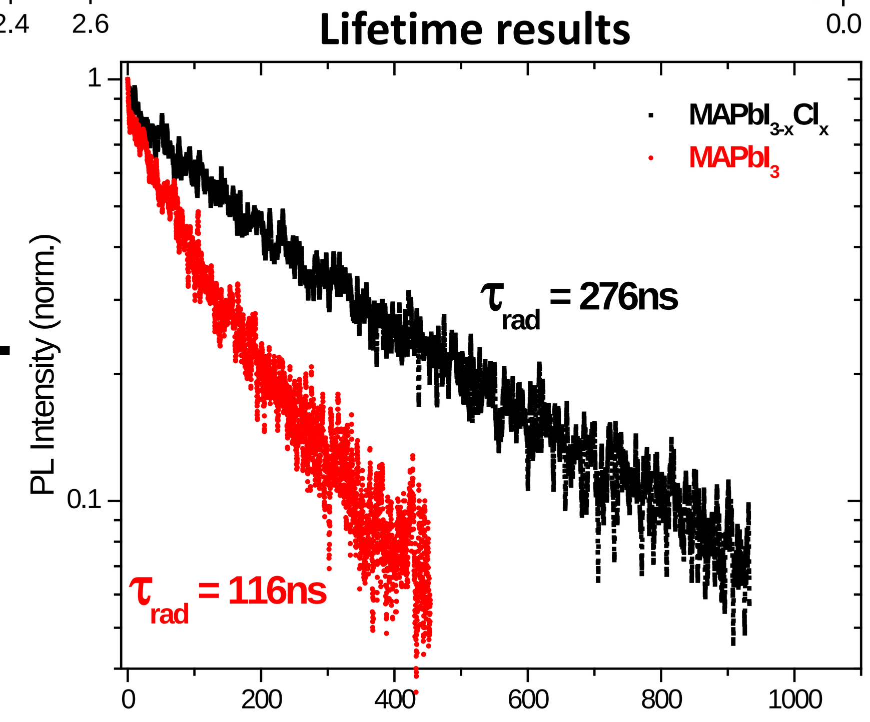
SSPG measurements



Balberg plot For $MAPbI_3$ →



Photoluminescence Lifetime results



$$L_D = \sqrt{2\frac{kT}{e}(\mu\tau)}$$

$$(\mu\tau)_{min} = 2.9\times10^{-8}\ \frac{cm^2}{V}$$

$$\mu_{min} = 0.25 \pm 0.06\ \frac{cm^2}{Vsec}$$

Upper bound for the mobility of the minority carriers!

Conclusions

- By combining Photoconductivity and Diffusion length measurements, we can reliably determine the mobility-lifetime products of the majority and minority charge carriers in $MAPbI_3$ films and find them to be in the same order of magnitude.
- We find that SSPG can be a reliable method to determine the ambipolar diffusion length of the charge carriers in $MAPbI_3$ films prepared via different preparation methods and find that for the $MAPbI_3$, L_D = 388±24nm, while for the $MAPbCl_xI_{3-x}$ film, L_D > 700 nm.
- The upper bound for the mobility of the minority carriers is found be 0.2-0.3 cm^2/Vsec.
- γ is found to be ~0.5, and preliminary results show that L_D is not dependent on the light intensity.
- We can explain our results using the generalized one-recombination level model.

Summary of the results

Material	σ_{dark} [1/Ωcm]	γ	L_D [nm]	τ_{rad}[ns]	$(\mu\tau)_{min}$ [cm^2/V]	$(\mu\tau)_{maj}$ [cm^2/V]	μ_{min} [cm^2/Vsec]
$MAPbI_3$	1.4×10^{-8}	0.42±0.01	388±24	116	2.9×10^{-8}	8.1×10^{-8}	< 0.25
$MAPbCl_xI_{3-x}$	7.2×10^{-8}	0.40±0.02	≥ 700	276	9.4×10^{-8}	1.4×10^{-7}	< 0.34

Acknowledgements

We thank the Leona M. and Harry B. Helmsley Charitable Trust, Israel Ministry of Science and the Israel National Nano-Initiative for partial support.