Effects of 6 MeV electron radiation on multi-colored commercial LEDs

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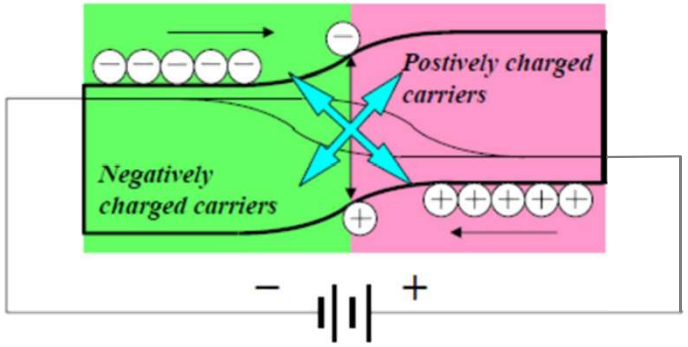
Introduction: Light-Emitting Diodes

LEDs are PN junctions based on direct bandgap semiconductors.



Some advantages compared to more classical sources:

- Fast ON-OFF switch time
- Low dimensions and weight
- High mechanical resistance and long light lifetime
- High efficiency

Inevitable deployment in radiation-rich environments.

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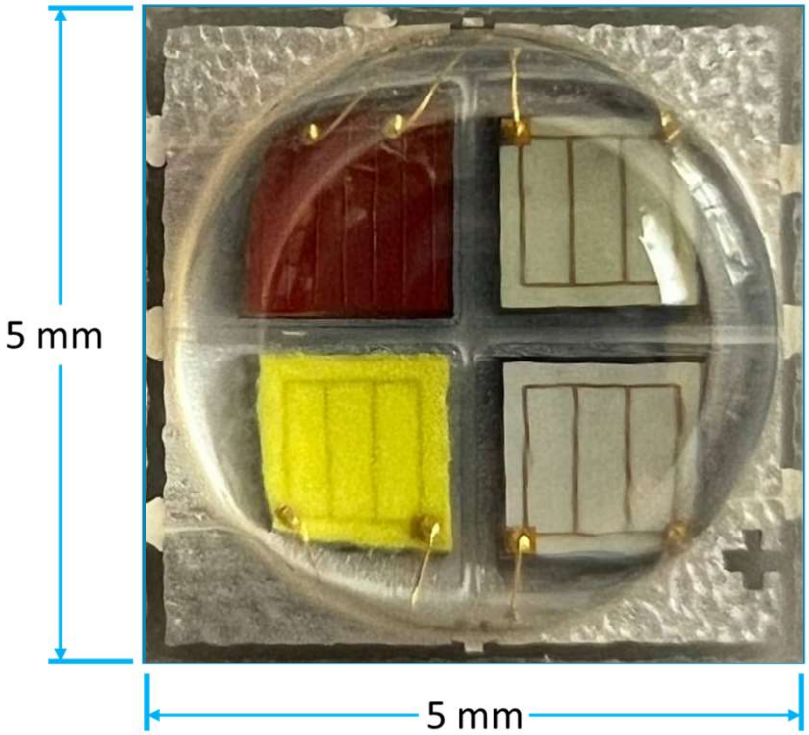
Setup: Devices under test

Cree XM-L Color Gen1.

Same used in *Gamma Ray Effects on Multi-Colored Commercial Light-Emitting Diodes at MGy Level., L. Weninger et al. Electronics* ***2023****, 12, 81.*

Multiple colors close together, which can be driven independently.



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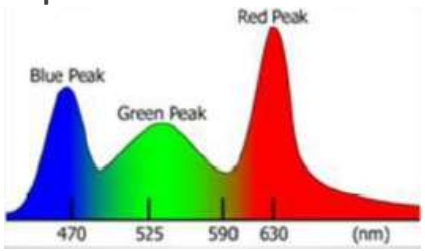
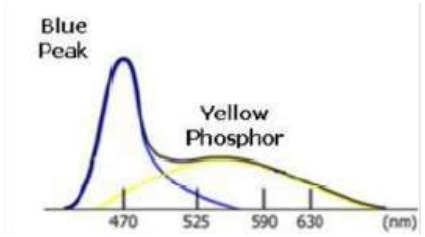
Setup: Devices under test

Two techniques for white LEDs

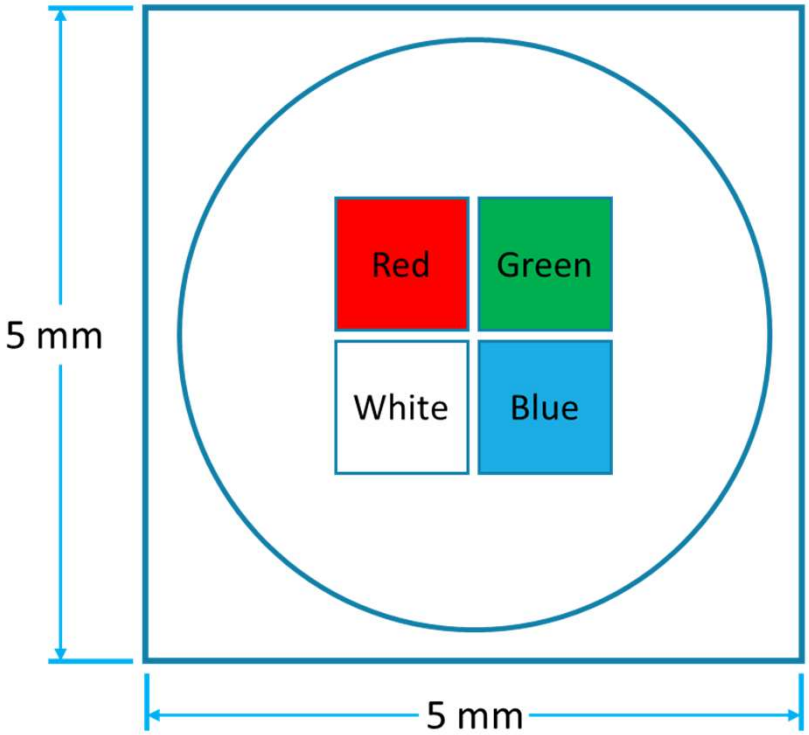
- RGB



- Blue + phosphor layer

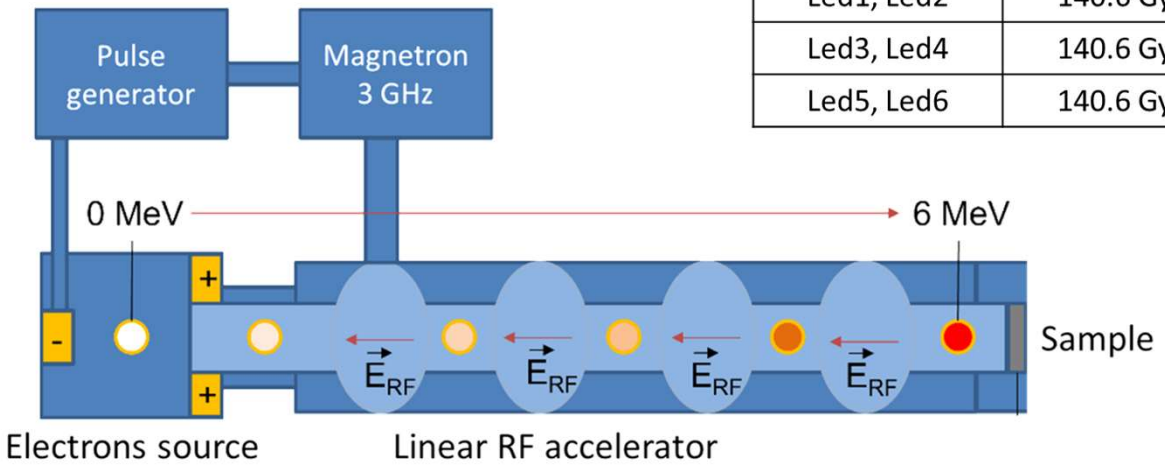


Under irradiation, we can compare the behavior of different LED technologies.



Setup: Irradiation conditions

6 MeV ORIATRON e⁻ beam



Samples	Dose rate	Irradiation time	Final dose
Led1, Led2	140.6 Gy/s	18 minutes	150 kGy
Led3, Led4	140.6 Gy/s	119 minutes	1 MGy
Led5, Led6	140.6 Gy/s	237 minutes	2 MGy

All devices were in open-circuit configuration.

All doses are expressed in Gy(H_2O).

LED: External Quantum Efficiency

External Quantum Efficiency (EQE) characterization

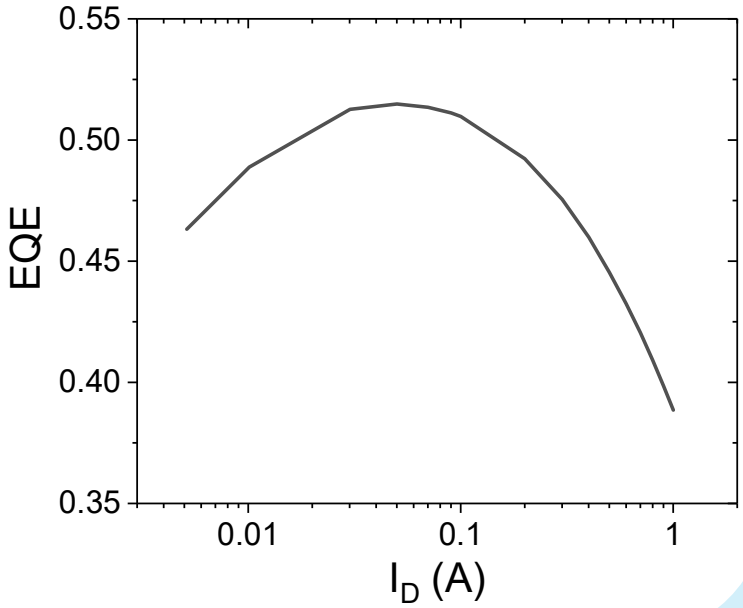
$$EQE = \frac{\Phi_{ph}}{\Phi_{el}}$$

Where:

Φ_{ph} is the number of emitted photons per second;

Φ_{el} is the number of injected electrons per second.

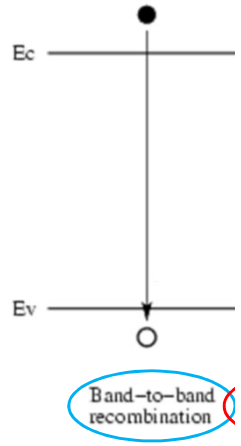
As such, the EQE is function of the drive current (I_D), which results in the characteristic bell shape.

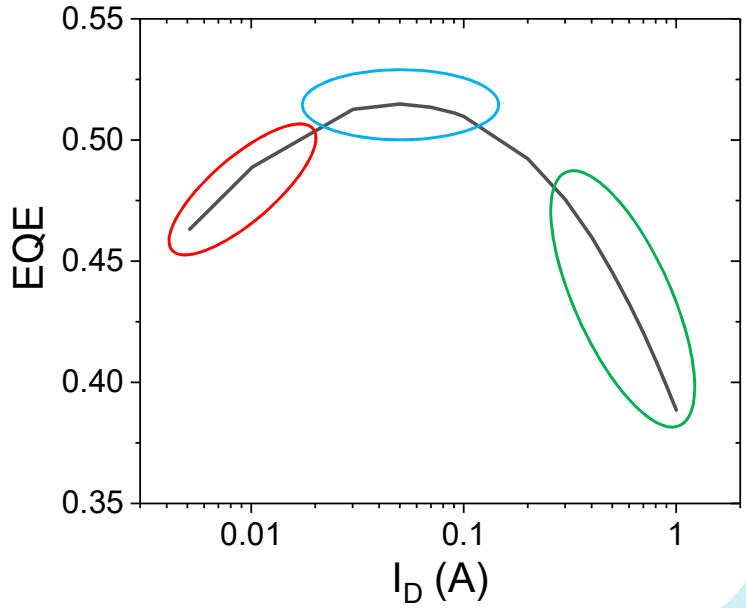


LED: External Quantum Efficiency

The competition among three e^--h^+ recombination processes explain the bell shape:

- Radiative recombination
- Shockley-Reed-Hall (trap-assisted) recombination
- Auger recombination (mainly)





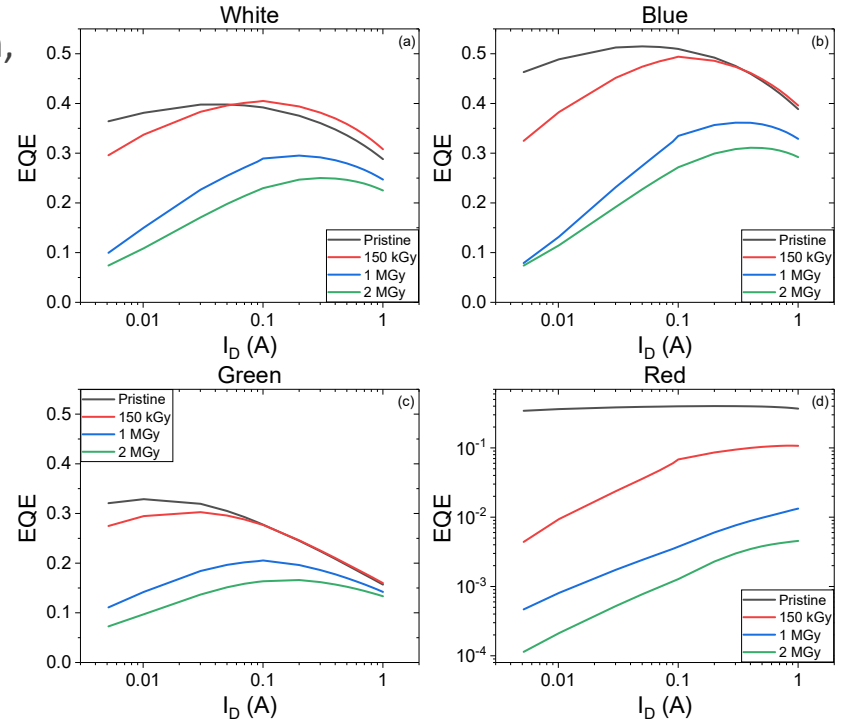
Results: EQE vs dose

All colors show a **dose-dependent** EQE degradation, mainly in low-current regime.

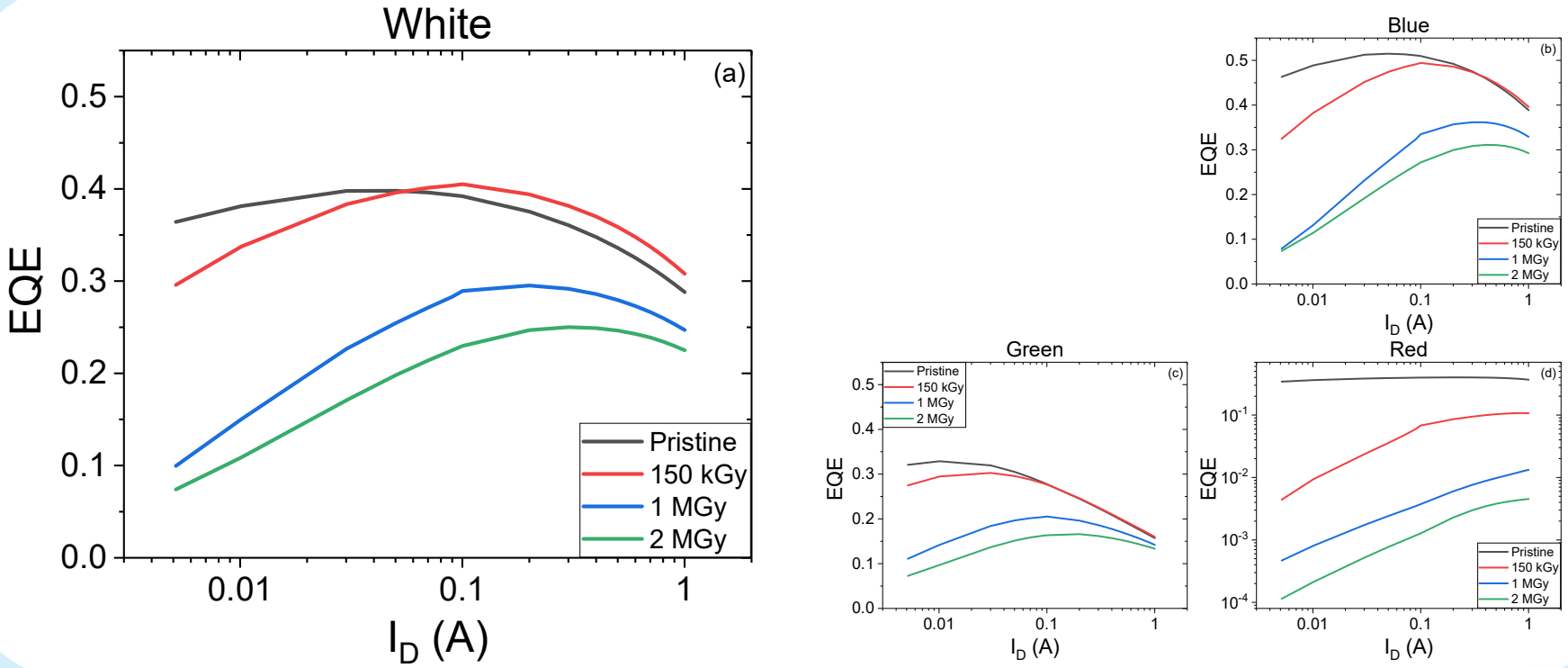
This is explained by the **generation of traps** due to the incoming electrons, which enhances the SRH recombination.

The EQE degradation shows a **saturating behavior** with cumulated dose.

This could be explained by a physical limit in the number of traps that can be present inside the junction.

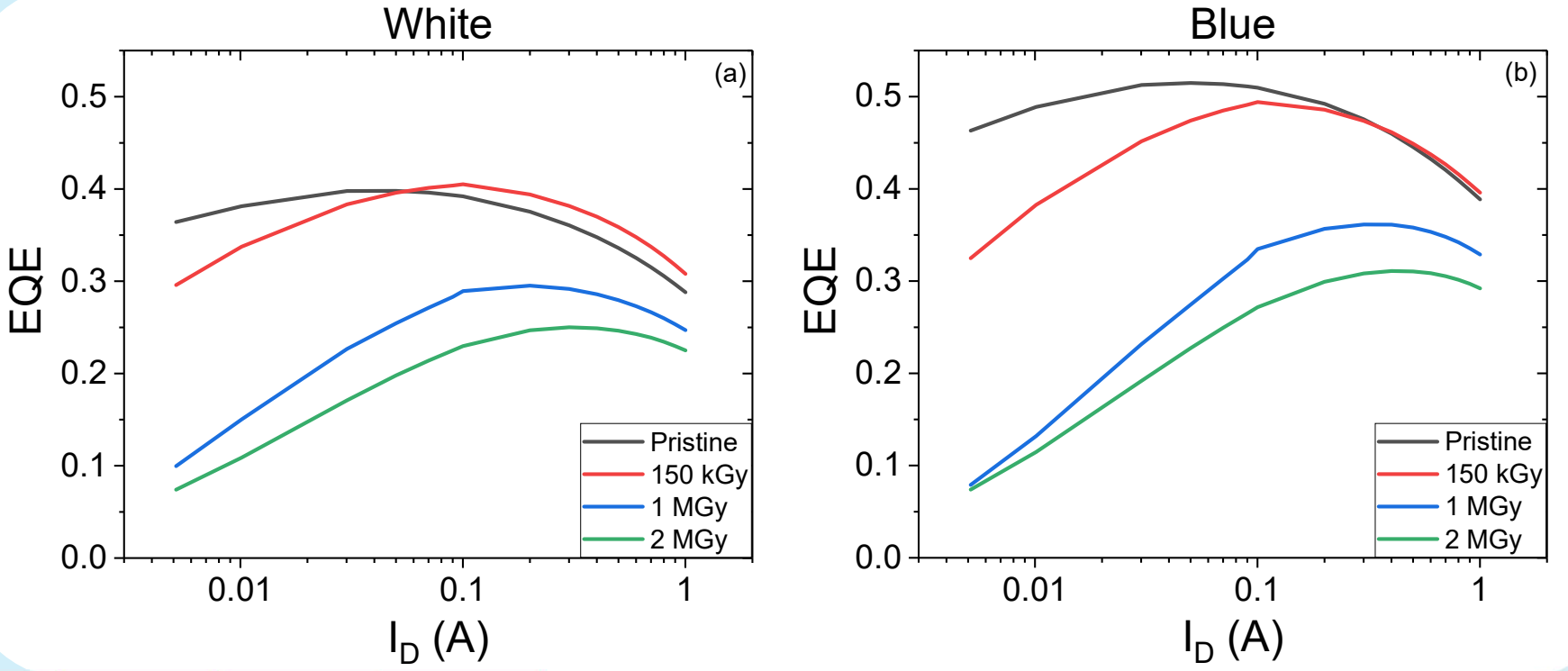


White LED: Depending on the probing current, the efficiency, hence the radiation-induced variation in optical power, changes.



It’s very important to test the EQE at different currents!

White vs Blue LED: The improved EQE of the white LED could be explained by an increased emission of the **phosphor layer.**



	I_D (A)	White	Blue
Var. % after 2 MGy	0.0051	-79.881 %	-83.251 %
	0.1001	-41.810 %	-46.391 %
	1.0001	-21.482 %	-23.945 %

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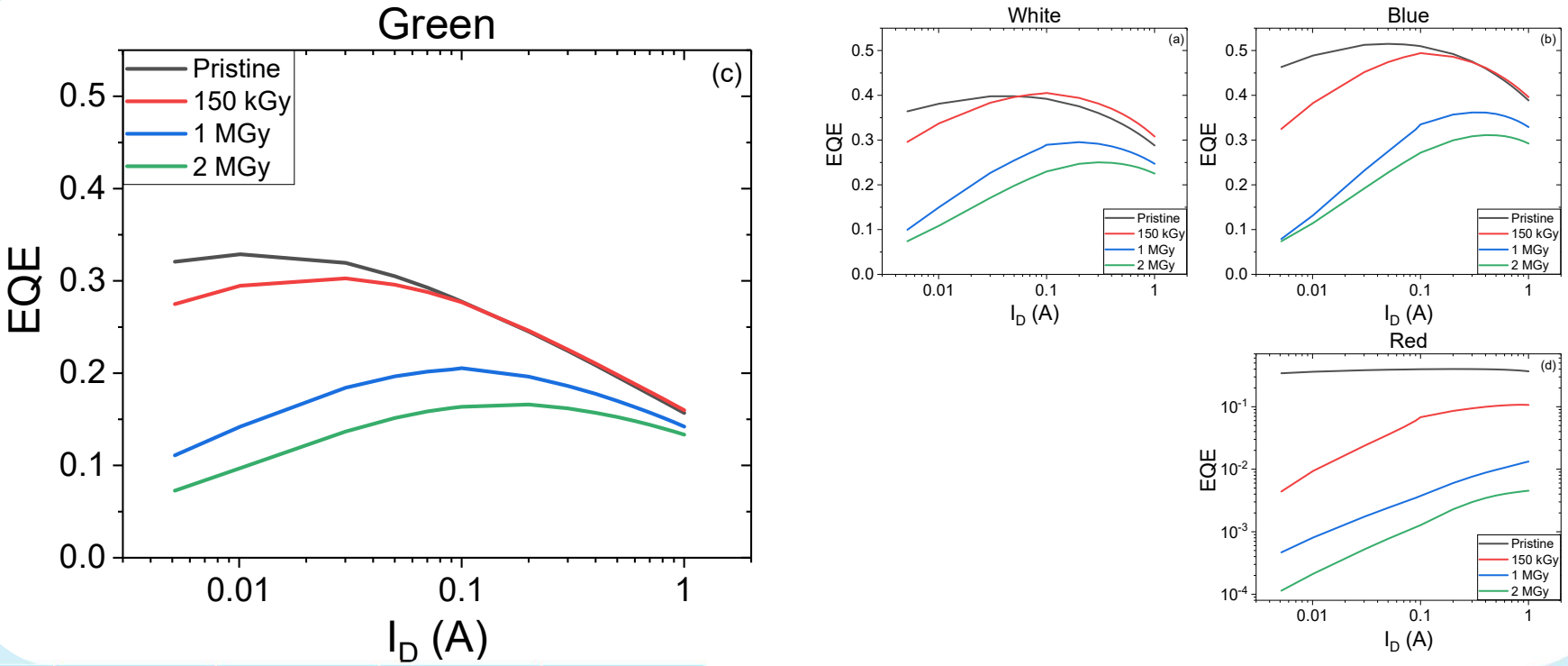
Green LED: The most radiation resistant, but in high current regime.



	I_D (A)	White	Blue	Green
Var. % after 2 MGy	0.0051	-79.881 %	-83.251 %	-77.808 %
	0.1001	-41.810 %	-46.391 %	-41.701 %
	1.0001	-21.482 %	-23.945 %	-15.521 %

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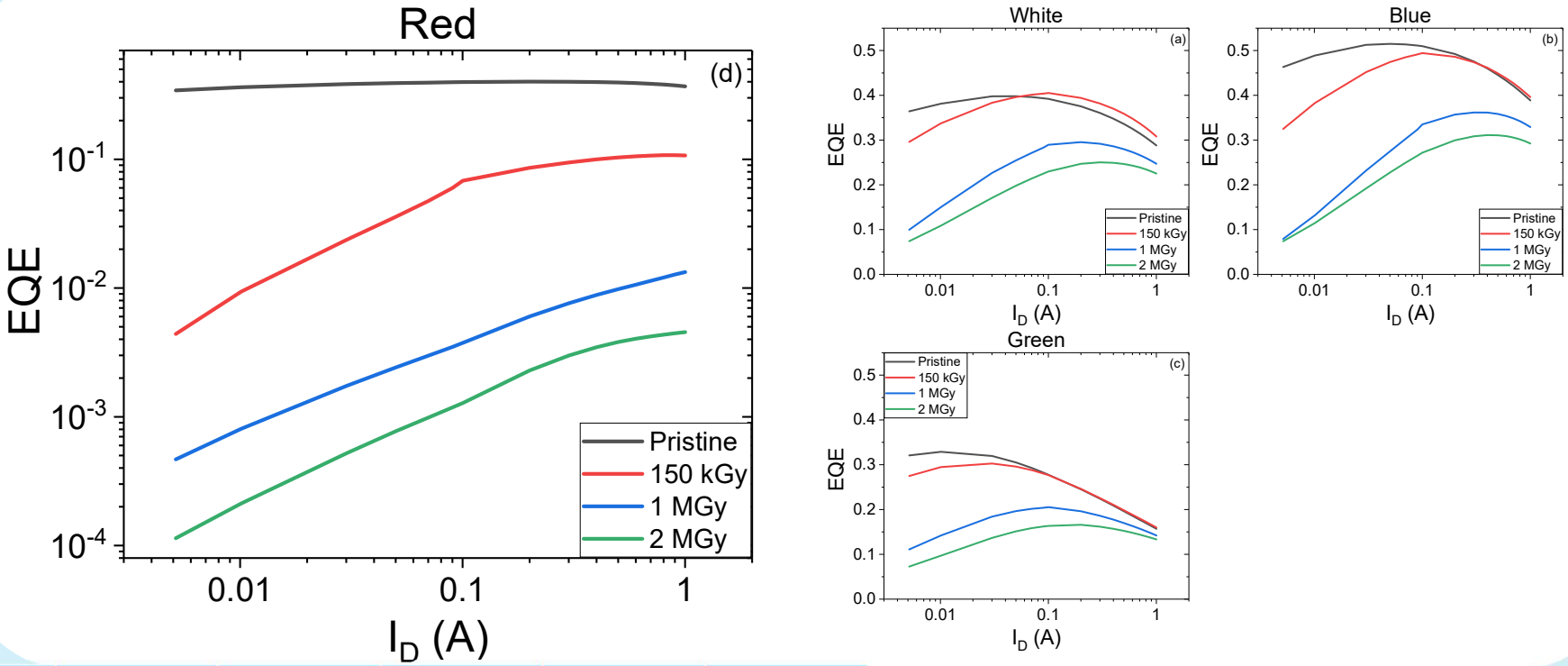
Red LED: The most sensitive → different technology



	I_D (A)	White	Blue	Green	Red
Var. % after 2 MGy	0.0051	-79.881 %	-83.251 %	-77.808 %	-99.967 %
	0.1001	-41.810 %	-46.391 %	-41.701 %	-99.674 %
	1.0001	-21.482 %	-23.945 %	-15.521 %	-98.734 %

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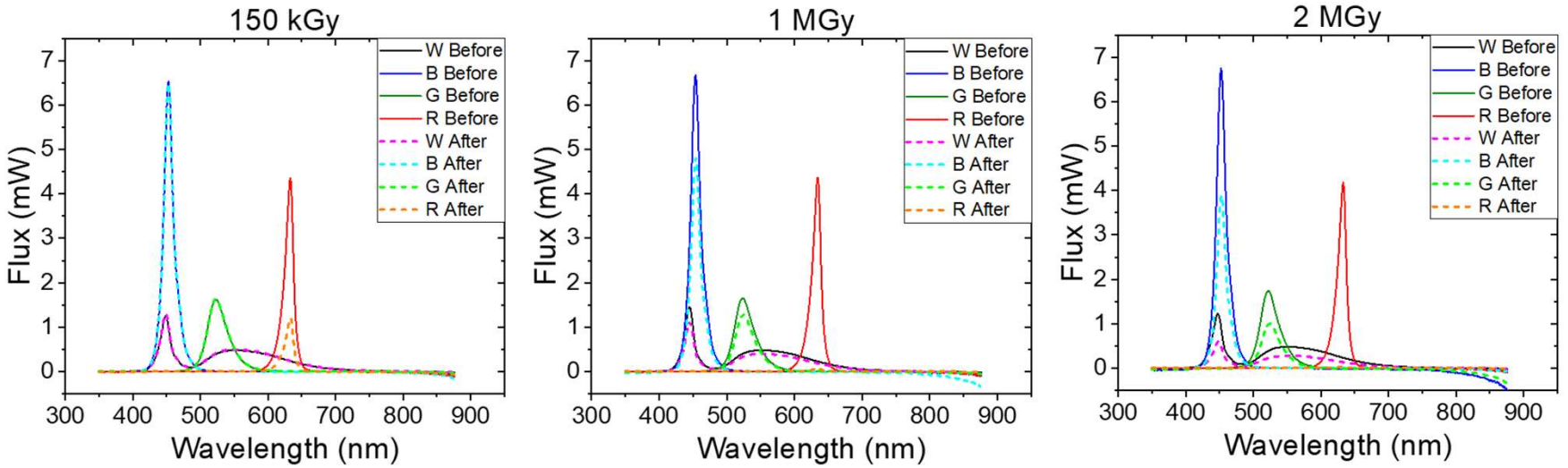
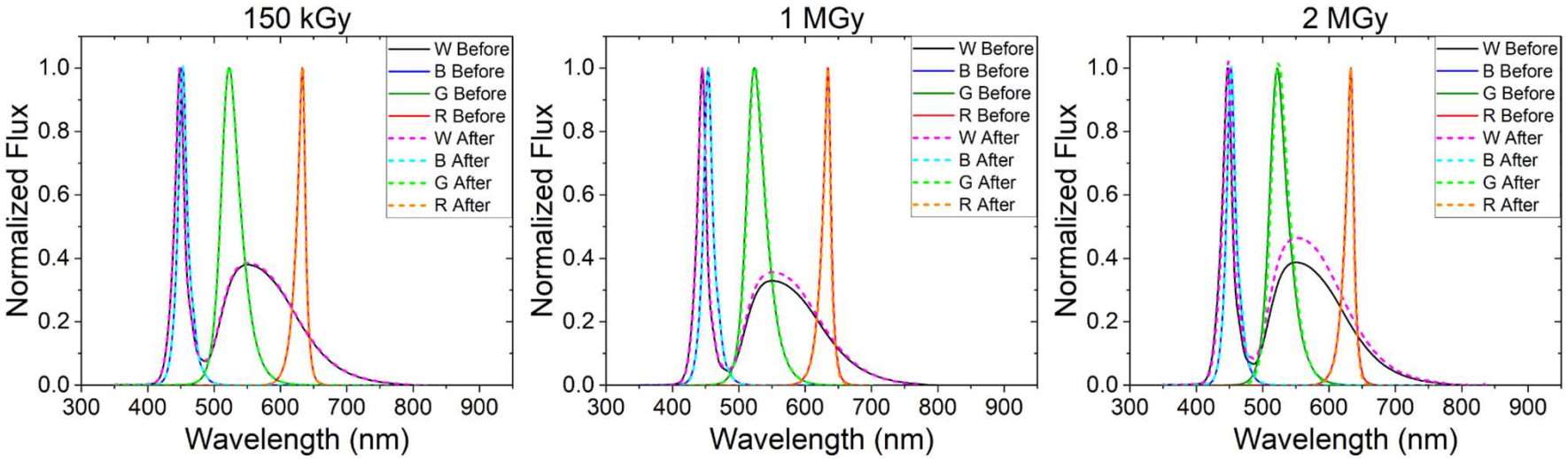
No radiation-induced wavelength shift has been observed…

Spectral response at 0.1 A



No radiation-induced wavelength shift has been observed…
but an increase in the phosphor layer emission.

Spectral response at 0.1 A



Conclusions

All colors show a **dose-dependent** EQE degradation, mainly in low-current regime.

It's very important to test the **EQE at different currents**.

The improved EQE of the white LED under electrons could be explained by an increased emission of the **phosphor layer. This is related to displacement damage.**

The **green** LED is the **most radiation resistant**, but it is already in high current regime in the investigated currents.

The **red** LED is the **most sensitive**. This is explained by the different technology (GaAs) used.

	I_D (A)	White	Blue	Green	Red
Var. % after 2 MGy	0.0051	-79.881 %	-83.251 %	-77.808 %	-99.967 %
	0.1001	-41.810 %	-46.391 %	-41.701 %	-99.674 %
	1.0001	-21.482 %	-23.945 %	-15.521 %	-98.734 %

Thank you for your attention!

LUCA WENINGER

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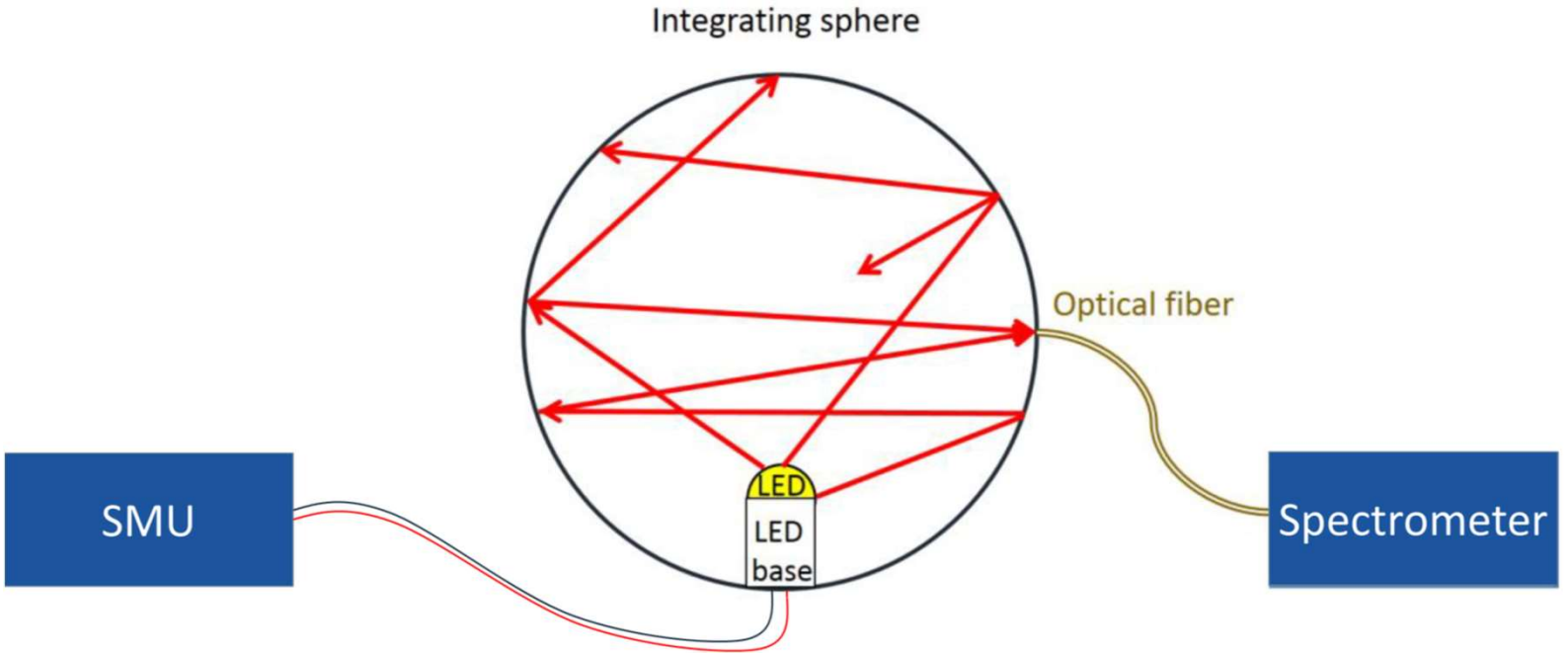
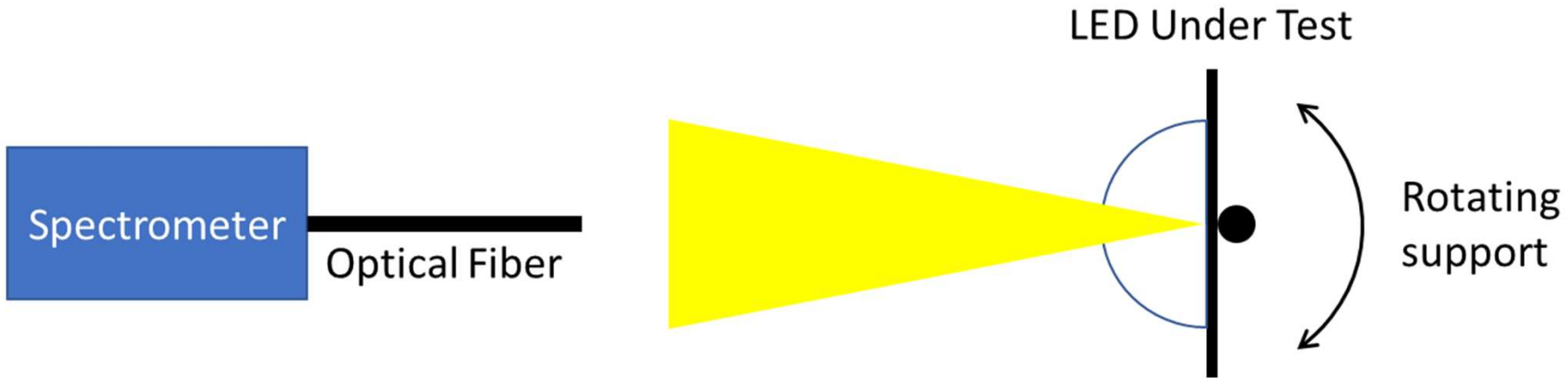
Extras

Setup: Integrating sphere



Setup: Diffusion pattern analysis



Results: Diffusion pattern