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VLSI Laboratory המעבדה ל-

AdQuanta

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Optimizing the Design of Radiation Detectors Using Nanostructures

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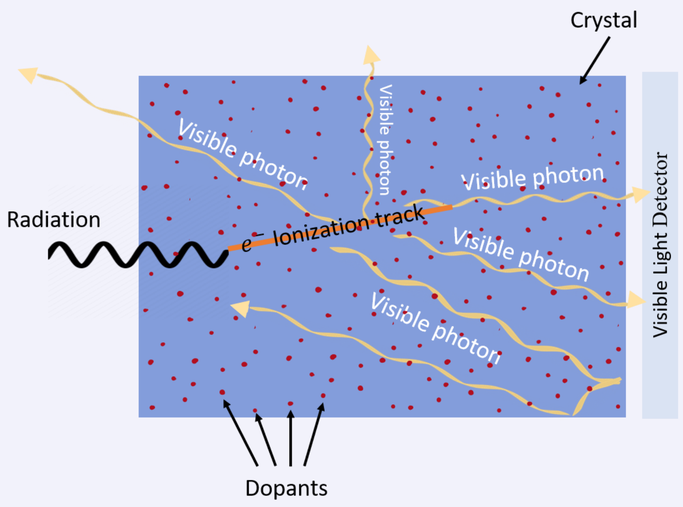
Scintillator Based Radiation Detectors

- High energy photon incident on a scintillator bulk generates a single electron
- The electron creates e-h pairs that recombine in dopants to create visible photons

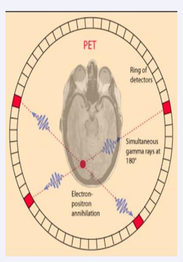


Project Goal

Develop a new tool for the design and optimization of novel high energy radiation detectors (Scint City)

Applications

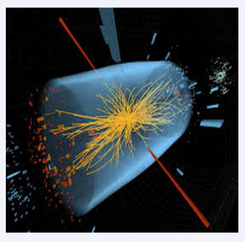
PET Scans



CT Scans

Mammography and X-ray Imaging

High Energy Physics CERN



Night Vision

Theoretical Basis

- First an expression for spontaneous emission rate for multi-layers nanostructures was derived
- The emission rate of a single dopant is given by :

$$\sum_{\sigma}\Gamma(\omega,\theta,t,\sigma,\vec{n},\vec{d}) = \frac{k_3 l_3^2}{k_1^3}\left(k_1^2\frac{\varepsilon_1}{\varepsilon_3}\left|\frac{T_{\parallel s\uparrow}}{l_1}\exp(il_1 t)\right|^2 + \left|T_{\parallel p\uparrow}\exp(il_1 t)\right|^2 + u^2\left|\frac{T_{\perp p\uparrow}}{l_1}\exp(il_1 t)\right|^2\right)$$

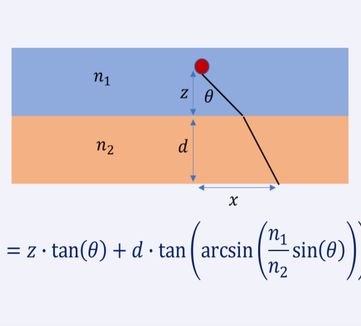
$$T_{\parallel s\backslash p\uparrow} = \frac{t_{13,s\backslash p}\left(1 + r_{12,s\backslash p}e^{2i(d-t)}\right)}{1 - r_{12,s\backslash p}r_{13,s\backslash p}e^{2il_1 d}},\ u = k_{max}\sin\theta,\ l_i = \sqrt{k_i^2 - u^2}$$

- Integrate to obtain the total effective emission of a structure

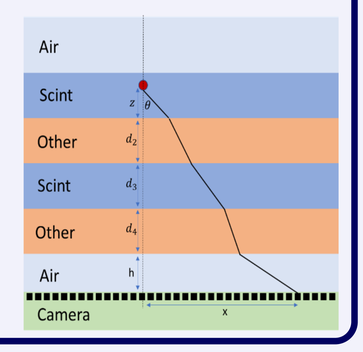
$$\Gamma_{\mathrm{eff}}(\theta,\vec{n},\vec{d}) = \int d\omega Y(\omega)\int_0^L \frac{dz}{L}\sum_{\sigma=\{TE,TM\}}\Gamma(\omega,\theta,z,\sigma,\vec{n},\vec{d})$$

Processing Images with Multilayers Nanostructures

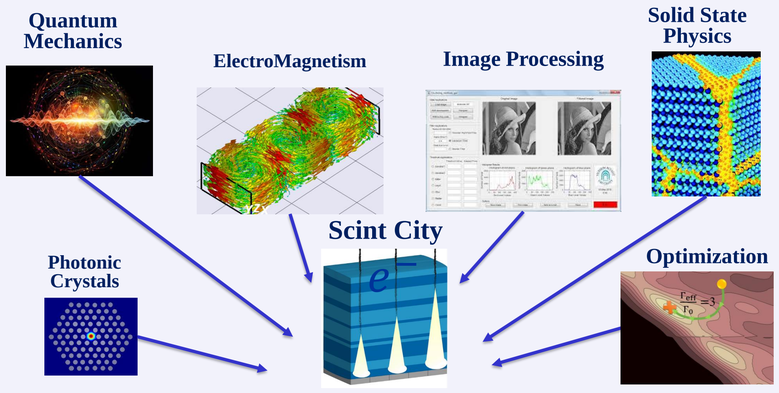
- Analytical calculation of the impulse response of multi-layers nanostructures
- Use Purcell effect and Snell's law
- A brand new visualization technique!



$$x = z\cdot\tan(\theta) + d\cdot\tan\left(\arcsin\left(\frac{n_1}{n_2}\sin(\theta)\right)\right)$$

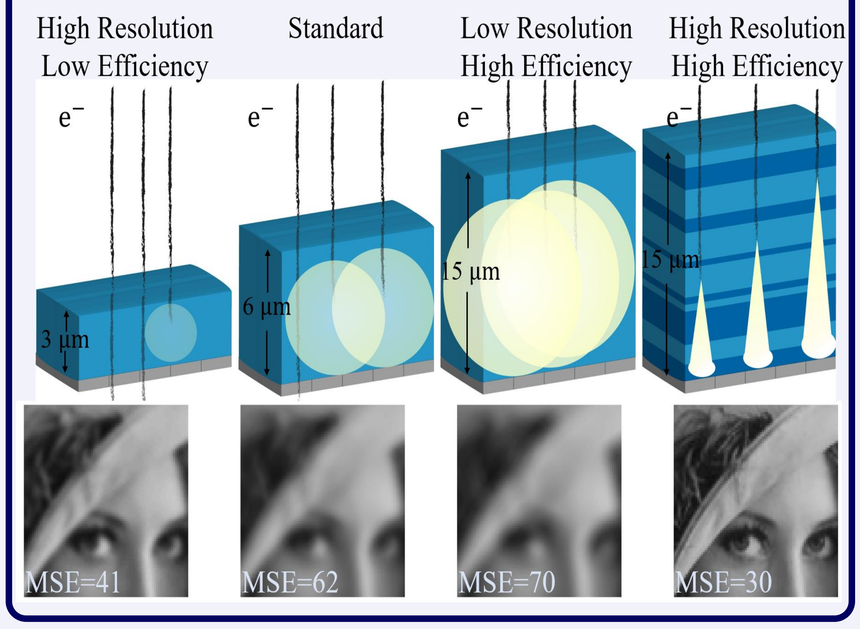


Multidisciplinary Engineering



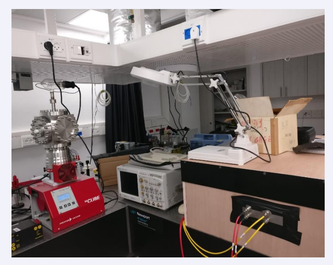
Thick or Thin Bulk
Getting the Best of Both Worlds

- The novel nano-structures overcome existing efficiency-resolution trade-offs



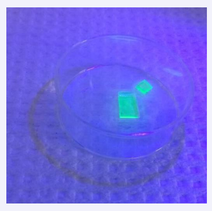
Immediate Impact

- New scintillator lab in the Solid-State Institute



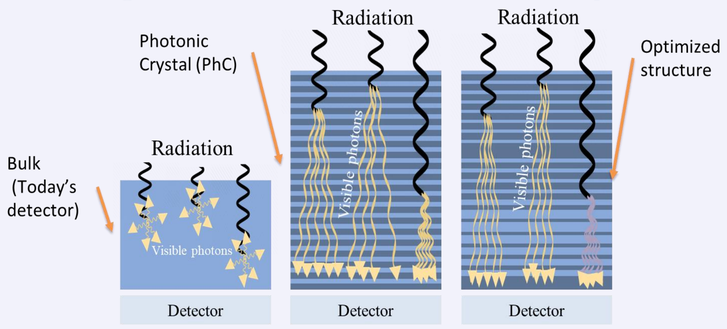
- X-ray detectors based on new design techniques manufactured and tested in CERN

- Design of efficient UV sources for harmless disinfection

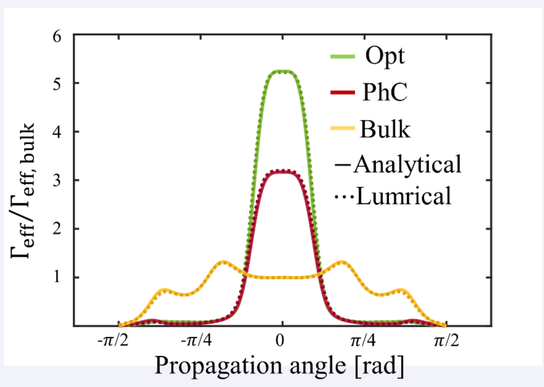


Optimizing Nanostructures for X-ray Detection

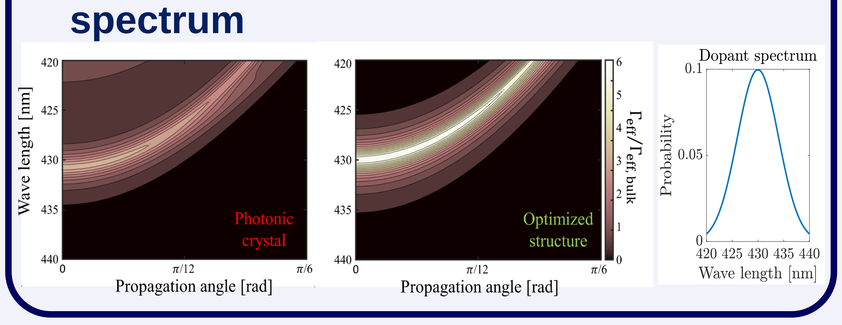
- Two detectors for X-ray imaging were designed with the new technique



- The newly designed detectors significantly outperform current detectors

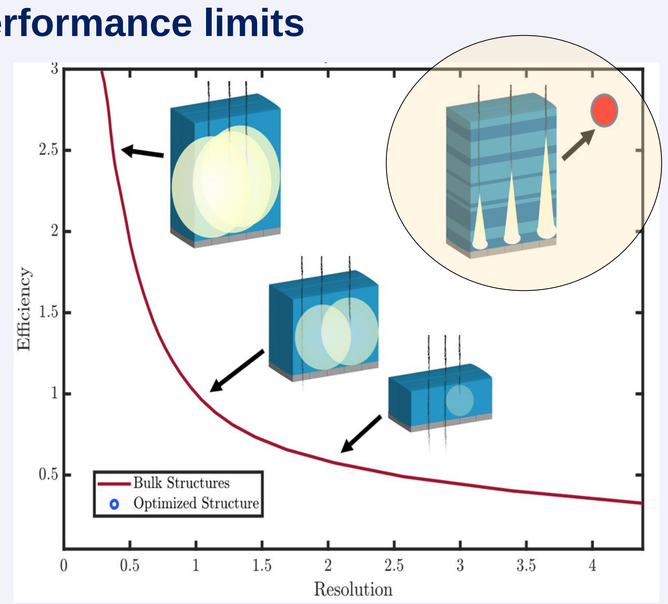


- Peak of the structures' enhancement match the peak of the emitters' spectrum



Overcoming Traditional Detector Design Trade-offs

- Existing designs follow a standard efficiency-resolution curve
- Resolution always traded-off for efficiency and vice-versa
- Nanostructures shatter the current performance limits



$$\mathrm{Efficiency} = \frac{\int \mathrm{PSF}(x)dx}{\int \mathrm{Standard\_PSF}(x)dx}$$

$$\mathrm{Resolution} = \frac{\mathrm{Cut\ off}(\mathrm{FFT}\{\mathrm{PSF}\})}{\mathrm{Cut\ off}(\mathrm{FFT}\{\mathrm{Standard\_PSF}\})}$$

Conclusions

- Nano-structures can implement novel High Energy Radiation (HER) detectors that overcome the traditional resolution-efficiency trade-off
- A multidisciplinary project, to achieve breakthroughs in HER detector design
- Scint City – our new tool, capable of designing optimized HER detectors for a wide range of applications