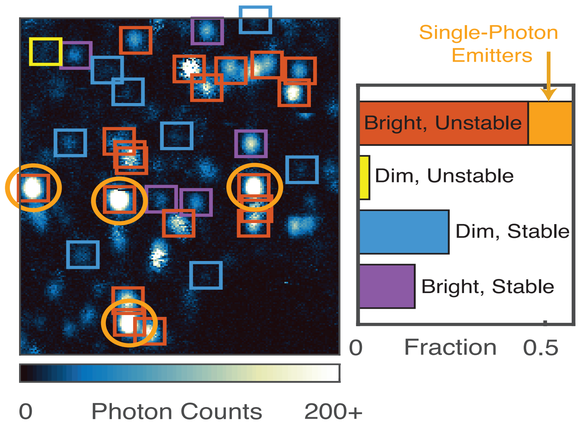
Efficient Analysis of Photoluminescence Images for the Identification of Single-Photon Emitters (SPE)

Leah Narun, SEAS 2022
Mentors: Professor Lee Bassett, Rebecca Fishman
Quantum Engineering Laboratory, Electrical and Systems Engineering

Penn University of Pennsylvania University Scholars

⟨Q|E|L⟩ Quantum Engineering Laboratory

Abstract



Basis for Detection

Single-photon-emitting defects appear as **Gaussian point-sources** in two-dimensional photoluminescence (PL) images, enabling their detection via image analysis.

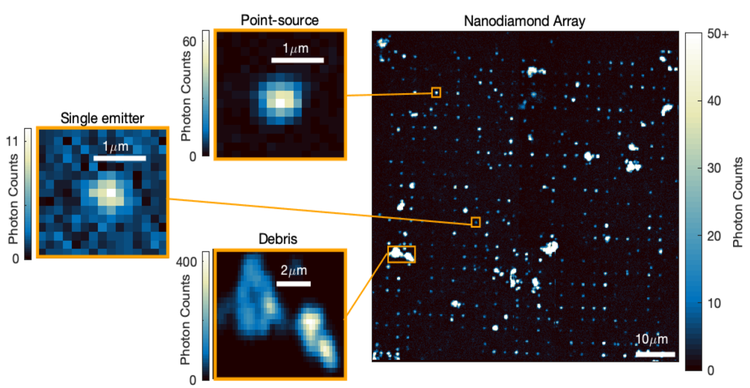
Detection Criteria

Signal to noise ratio (SNR) $= \frac{\text{Intensity}-\text{Background}}{\sqrt{\text{Background}}}$ **Gaussian Width** $\cong 0.21 * \frac{\lambda}{NA}$

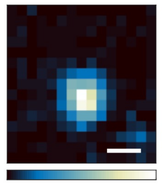
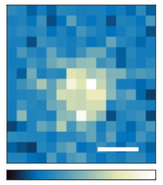
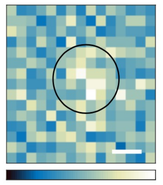
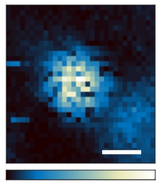
Goodness of Fit $\chi_r^2 = \frac{1}{F} * \sum_{n=1}^{N} \frac{(O_i - M_i)^2}{\sigma_i^2}$ **Eccentricity (e)** $= \sqrt{1 - \left(\frac{\min[\sigma_1, \sigma_2]}{\max[\sigma_1, \sigma_2]}\right)^2}$

M_i = fit, O_i = measured, σ_i = noise,
F = degrees of freedom

Example Emitters in Large Area PL Image



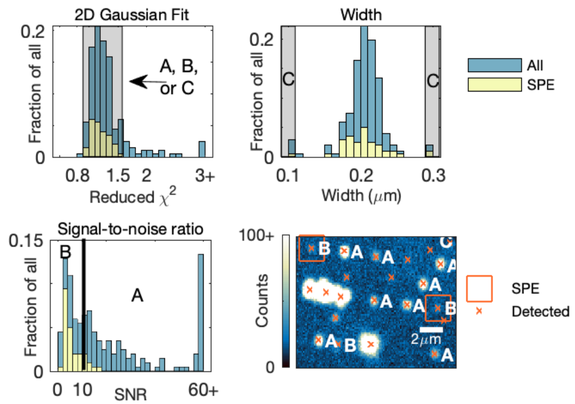
Emitter Classification

Group A	Group B	Group C	Group D
SNR > 10	2 < SNR < 10	2 < SNR < 10	SNR > 10
$0.8 < \chi_R^2 < 1.5$	$0.8 < \chi_R^2 < 1.5$	$0.8 < \chi_R^2 < 1.5$	0 < e < 0.66
Width within limits	Width within limits	Width at limits	Width within limits
			
Photon Counts	Photon Counts	Photon Counts	Photon Counts
bright, stable	dim, stable	dim, blinking	bright, blinking

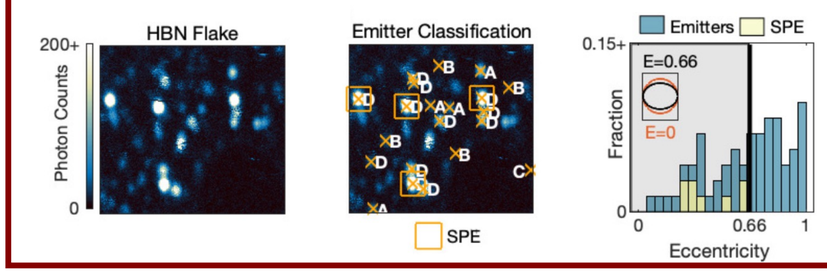
Material Application

Nanodiamond Array: stable, spatially-coordinated emitters

- With fluorescent nitrogen-vacancy defects that frequently overlap

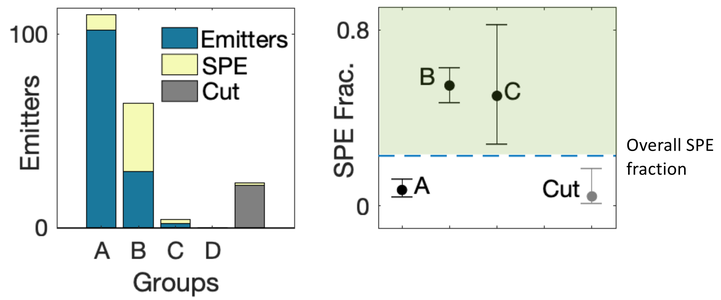


Hexagonal Boron Nitride (H-BN): unstable, randomly-distributed emitters

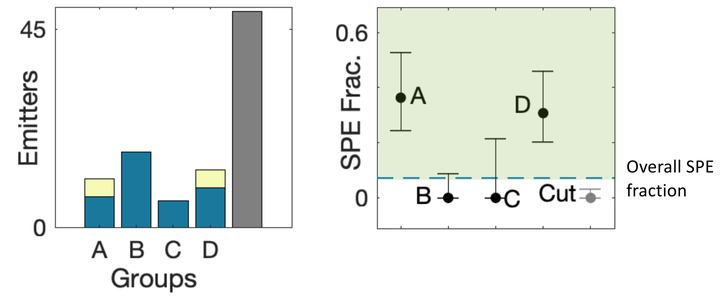


Improved SPE Discovery

Nanodiamond Array



Hexagonal Boron Nitride Flake



Summary and Outlook

- The method presented here provides a general, flexible framework for efficiently screening new materials for single-photon emitters [1].
- While we have demonstrated the utility of this method for commonly studied defect hosts like h-BN and diamond, it can also be applied to promising yet largely unexplored materials.
- Potential new hosts include compound semiconductors like magnesium and strontium oxides, group II-VI materials like zinc sulfide, complex metal oxides like yttrium orthosilicate, and perovskites [2].

Acknowledgements

The author thanks the University Scholars program for their financial support of this research project, Rebecca Fishman and Prof. Lee Bassett of the Quantum Engineering Laboratory for their mentorship, and Henry Shulevitz and Raj Patel for sharing their nanodiamond and h-BN photoluminescence data, respectively, for the development of this method.

References

[1] Narun, L. R., Fishman, R. E. K., Shulevitz, H. J., Patel, R. N., Bassett, L. C. (2021). *Efficient Analysis of Photoluminescence Images for the Classification of Single-Photon Emitters*. arXiv:2112.05654v1
[2] Bassett, L. C.; Alkauskas, A.; Exarhos, A. L.; Fu, K. M. C. Quantum defects by design. Nanophotonics 2019, 8, 1867–1888.