Mitigation of Electrical Cross-Talk in Silicon Single-Photon Avalanche Diode (SPAD) Arrays Using Binary Classification

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Introduction

- Silicon SPAD arrays are widely used in applications such as biophotonics, 3D sensing, and LiDAR systems (e.g., Apple iPhone's Face ID and depth sensors).
- SPADs achieve high detection efficiency due to their operation in 62.5 V (breakdown voltage), in the Geiger mode, which enables single-photon sensitivity through significant avalanche gain.

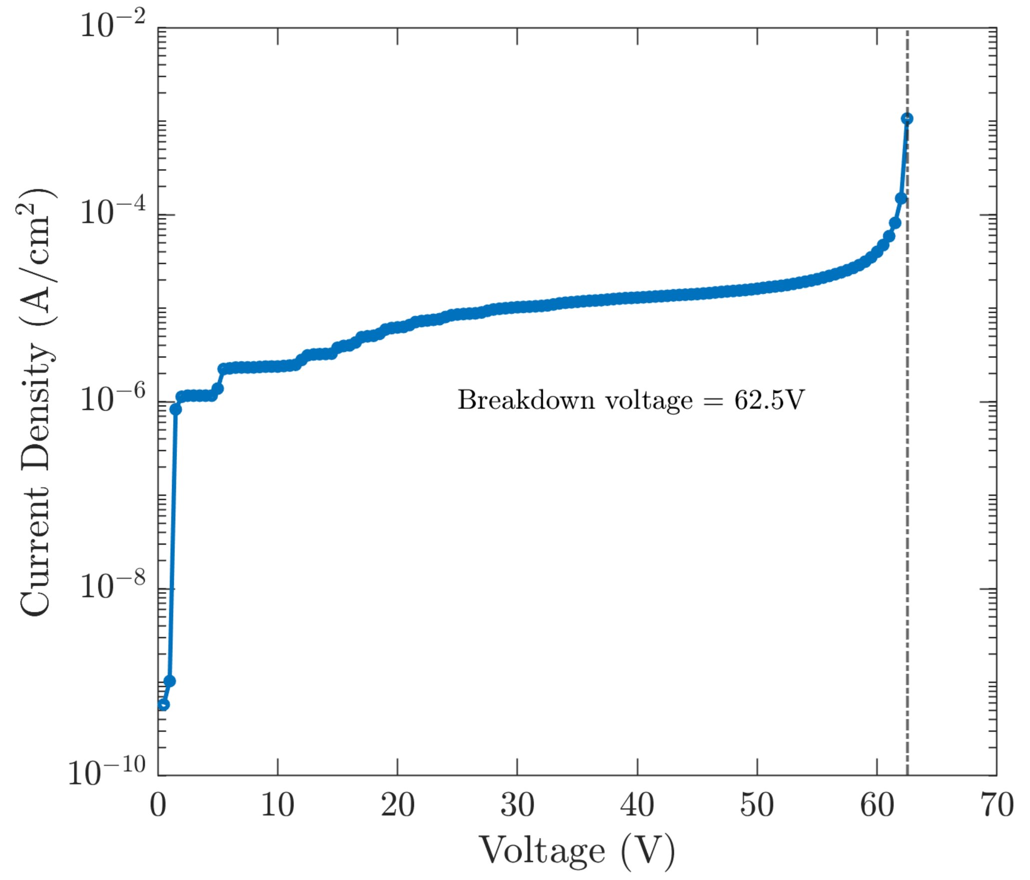

Figure 1: IV Curve

The Crosstalk Challenge

- Electrical crosstalk between neighboring SPAD pixels leads to false photon events, degrading image resolution and measurement accuracy.
- Pixel spacing can be optimized to suppress inter-pixel interference.
- Manual optimization is time-consuming and not scalable for industrial design, despite TCAD tools like Silvaco simulation.

Proposed Approach

Research Goal: Develop a machine learning-assisted design framework to automatically predict the optimal pixel spacing (pitch) that minimizes electrical crosstalk.

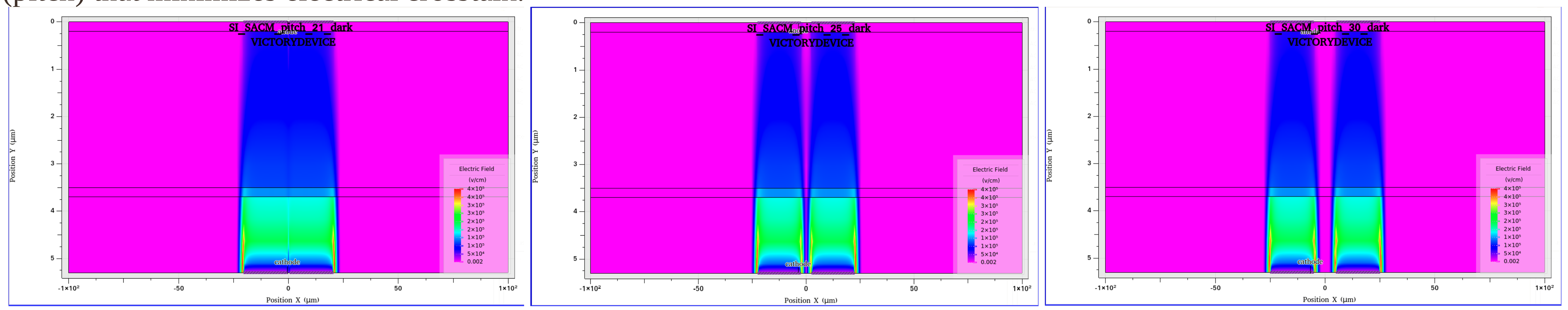

Figure 2: Electric Fields showing variable pitch sizes of 21, 25, and 30 (left to right respectively), simulating cross-talk behavior

Accelerate crosstalk-aware pixel layout optimization by combining the TCAD simulations above with ML model below.

Workflow:

- Generate training data using SILVACO by varying pixel pitch.
- Extract features such as electric field distribution, peak field values, and potential gradients.
- Train a Binary Classification model to predict crosstalk severity.
- Use the trained model to identify the optimal pitch, minimizing crosstalk.

Conditions: Fixed pixel size, vary only the pitch between pixels to simplify the optimization.

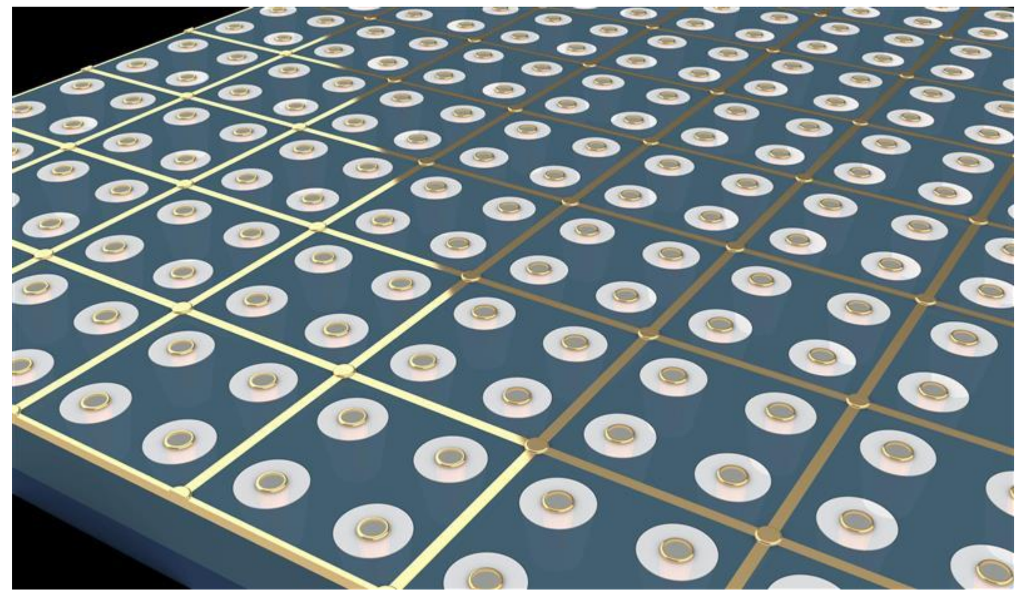

Figure 3: SPAD Arrays

Results

Cost Function: The Mathematical equation behind Logistic Regression

$$J(\theta) = -\sum_i \left(y^{(i)} \log(h_\theta(x^{(i)})) + (1-y^{(i)}) \log(1-h_\theta(x^{(i)}))\right)$$

- Optimization with Binary Classification can **successfully classify cross-talk in SPAD layers**, reinforcing former research results.
- Model follows a systematic **architecture** with training involved from datasets obtained from Silvaco simulations.
- Predicted optimal pitch for minimal crosstalk occurs at 62.5 V. BC model supports this. Our ML-assisted approach achieves comparable results in significantly less time than manual optimization.

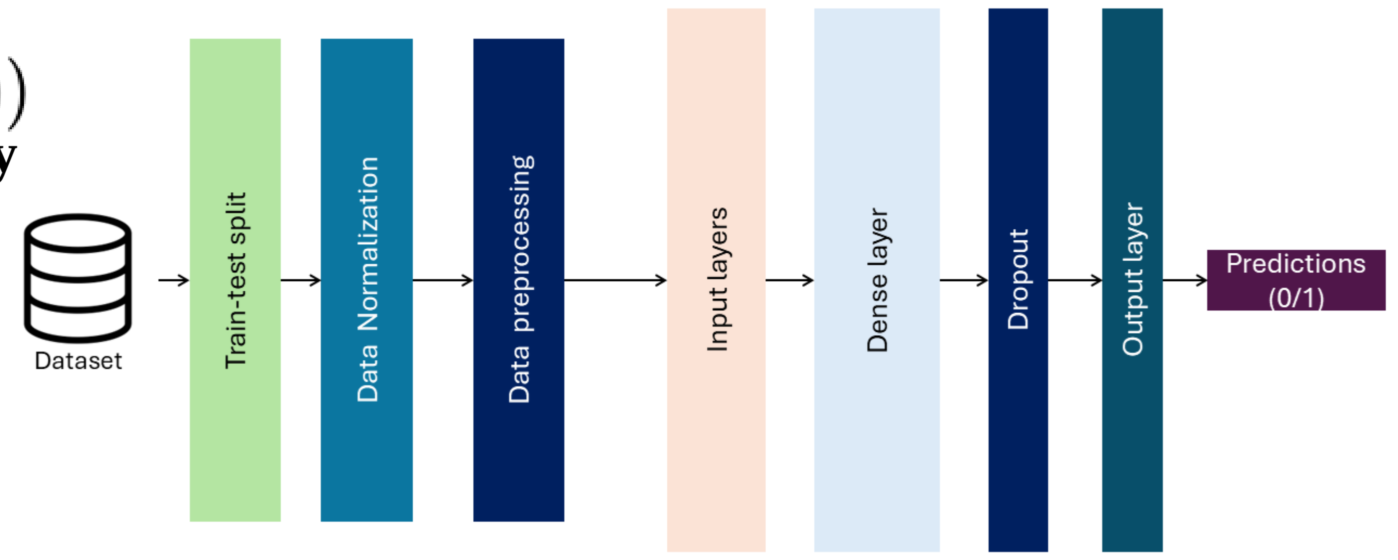

Figure 4: Machine Learning Model Architecture of Binary Classification

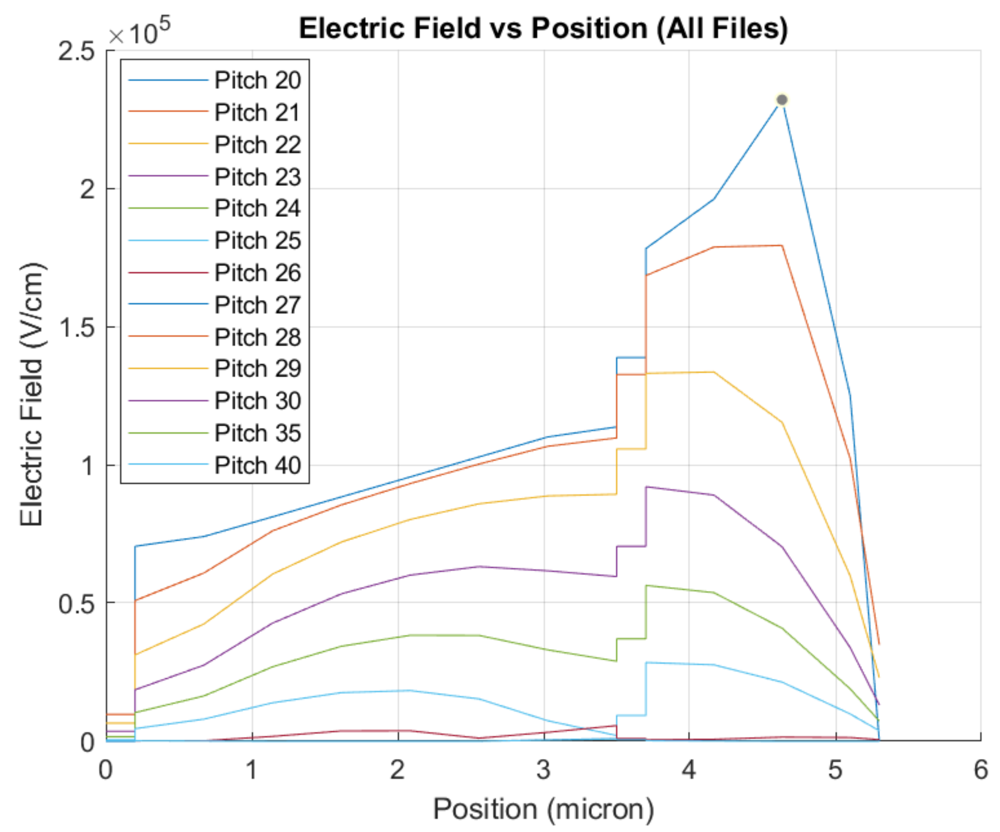

Figure 5: Plots of Electric Field against Position confirms initial hypothesis of successful identification of cross-talk after varying pitch sizes (original dataset)

$$\text{Accuracy} = \frac{\text{correct classifications}}{\text{total classifications}} = \frac{TP+TN}{TP+TN+FP+FN}$$

Conclusion

- Crosstalk mitigation in SPAD arrays is critical for high-fidelity photon detection.
- Our proposed TCAD + ML framework enables fast, scalable design space exploration.
- This approach has the **potential to accelerate SPAD array development** for industrial applications such as LiDAR and biomedical imaging.
- **Future Work:** Extend to 2D arrays, size of pixels and deploy real-time feedback into the layout toolchain.

References & Acknowledgements

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- S. Vinogradov, E. Popova, Status and perspectives of solid state photon detectors, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 952, 2020

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