AI-Driven Photoluminescence Modeling and Experimental Study of Luminescent Silicon Quantum Dot Ink for Quantum Communication Applications

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***Abstract*—Luminescent materials based on silicon are of good quality and at the same time, they can be used for integrated photonic systems meant for quantum communication. The present paper deals with the study of silicon luminescence from quantum dot ink as a quantum emitter. Moreover, it provides a model for the inked photoluminescence by employing machine learning. Four different regression models were used for the evaluation - MLP, Random Forest, Decision Tree, and Linear Regression. The optimised model, Random Forest got the highest accuracy based on MAE, MSE, and R^2 scores. This combination of quantum photonics and AI modeling gives an idea of the emission dynamics and also facilitates the invention of fast and efficient next-generation quantum communication technologies.**

Keywords—Silicon Quantum Dot Ink, Single-Photon Emission, Machine Learning (ML),LIME(Local Interpretable Model-agnostic Explanations),SHAP (SHapley Additive exPlanations).

I. INTRODUCTION

Quantum communication uses quantum phenomena like superposition and entanglement to provide secure data transmission. Single-photon sources (SPSs) are essential for the encoding of quantum information [1]. Silicon quantum dots (SiQDs) are being developed as suitable SPSs thanks to their special quantum confinement effects which allow for size- and emission- and high-photoluminescence efficiency [2]. While bulk silicon has an indirect bandgap, nanoscale SiQDs promote radiative recombination which is the main reason why they are good for photonic applications. Plus, their compatibility with CMOS production processes guarantees scalable,cost-effective integration with the existing microelectronic infrastructure[3].There is experimental proof that SiQDs can be trusted as single-photon emitters, for example, through the observation of photon antibunching via photon correlation spectroscopy [4]. The inclusion in dielectric matrices such as SiO_2 or Si_3N_4 not only increases the stability but also diminishes non-radiative losses and enables coupling with photonic structures that enhance the extraction of photons through Purcell [5].

The temporal coherence and narrow linewidths make them suitable for applications like quantum key distribution, entanglement swapping, and quantum interference.Currently, work is being done towards the printing of SiQD inks which would facilitate the use of various printing techniques such as inkjet and spin-coating for large-area, flexible, and scalable device fabrication [6]. The inks are capable of being deposited uniformly on different substrates and are being considered for both wearable devices and quantum photonics at chip scale. The key to the success of luminescence and the performance of the device are the surface passivation, solvent systems, and particle distribution [7]. It is true that there are challenges like room-temperature operation and electrically driven emission but still SiQDs keep showing great potential for future quantum networks and information systems [8].

The application of Machine Learning (ML) methods speeds up the process of producing luminescent quantum dot (QD) inks for quantum communication by the predicting and controlling synthesis and the photoluminescence behavior parameters. Different types of machine learning models such as Linear Regression, Decision Trees, Random Forest, and MLP are used to not only analyze but also control the behavior of emitted light and that of the entire device through the simplification of the data's complexity and allowances of its non-linear nature.