



REDUCED-ORDER ROBUST PARTICLE FILTERING FOR OPTOELECTRONIC STATE ESTIMATION IN DRIFT-DIFFUSION-REACTION SYSTEMS

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Abstract. In this work, we develop the real-time internal dynamics of such optoelectronic devices are governed by high-dimensional nonlinear partial differential equations (PDEs) of the drift-diffusion-reaction type, where the strongly nonlinear cubic reaction term corresponds to Auger recombination processes. A robust and computationally efficient Bayesian filtering framework for state estimation of charge carrier dynamics in metal-semiconductor heterostructures (e.g., In/Ag-AgInS₂). Traditional filtering approaches, such as the Extended Kalman Filter (EKF) and classical Particle Filters (PF), exhibit severe performance degradation when confronted with high-dimensional spatial discretizations, steep Schottky barrier-induced field gradients, and heavy-tailed non-Gaussian measurement noise typical of optoelectronic sensor data. To address these structural and computational challenges, we introduce the *Reduced-Order Robust Particle Filter* (RO-RPF). This method combines Proper Orthogonal Decomposition (POD)-based model reduction with a mixture-model robust likelihood. By projecting the high-dimensional PDE state onto a low-dimensional latent manifold, the RO-RPF substantially mitigates particle degeneracy and breaks the curse of dimensionality, while preserving full-order physical fidelity during the propagation of carrier dynamics. Numerical experiments demonstrate that the RO-RPF consistently outperforms classical baselines, preventing the weight collapse and linearization failures seen in standard methods. The results indicate that merging electro-optical physical models with robust reduced-order Bayesian inference enables reliable, scalable, and highly accurate state estimation for advanced optoelectronic devices.