Preface

Semiconductor quantum light sources based on quantum dots, such as triggered single- and entangled photon sources, are fascinating devices since they provide the ultimate control over the light emission process. Moreover, they deliver light states with superior optical and quantum optical properties. This includes high single-photon emission probabilities (brightness), low multiphoton probabilities (single-photon purity), and identical photon wave packets (indistinguishability), i. e., ultimately Fourier transform-limited photons. Furthermore, in recent years, triggered polarization- and time-bin entangled photon pair states have been demonstrated with very high fidelities and photonic cluster state generation. In the meanwhile the covered spectral range extends from the ultraviolet up to the telecom bands. From a more practical point of view, alternatively to optical excitation, the sources can be also electrically driven and therefore be very compact and robust. Many quantum photonic implementations will strongly benefit from their excellent properties, e. g., quantum communication, photonic quantum sensing, photonic quantum simulation, and optical quantum computing.

The aim of this textbook is to give an extensive experimental view onto the fundamental properties of quantum light states, their characterization methods, and their generation by quantum-dot-based light sources. The first two topics are discussed in a broader sense and are therefore relevant for all kinds of quantum light emitters, whereas for the photon generation process, we restrict ourselves on semiconductor-based quantum dots. This book targets physics and quantum engineering students at undergraduate and graduate levels, as well as research scientists, physicists, and engineers in academia and industry. It offers practical bases for understanding quantum light sources and for evaluating their performances. This book is written by experimentalists for experimentalists, while keeping rigor in the explanation of the theory necessary to understand the experiments. It is partly based on lecture notes of the *Semiconductor Quantum Optics* course and on the *Physics and Technology of Nanostructures for Quantum Optics* course for bachelor/master physics and photonic engineering students at the University of Stuttgart.

The book is organized in three parts and 14 chapters. Part I (Chapters 1–6) contains fundamentals of quantum light states and their classification, and it is therefore useful for understanding quantum light from all different kinds of quantum emitters. Besides a classical description of linewidth broadening effects, first- and second-order correlation functions (Chapter 1) and quantum specific aspects are also introduced. This includes a short introduction into the quantum theory of radiation and field quantization in open space and cavities, as well as a quantum description of the correlation functions necessary to adequately describe nonclassical light states such as photon number states (Chapters 3 and 4). In Chapter 5, all relevant single emitter properties such as linewidth, brightness, single-photon purity, photon coherence, photon indistinguishability, and degree of entanglement are covered together with experimental settings to benchmark these properties. In Chapter 6, cavity quantum electrodynamics (c-QED) is treated with

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a special emphasis on the interaction of a two-level system with a light field discussing also the so-called weak and strong coupling regimes of cavity QED.

Part II (Chapters 7–11) is devoted to semiconductor quantum dot specific topics. It starts with an introduction of the basic physical properties of quantum dots, including their electronic and optical properties (Chapter 7). Different excitonic configurations and their specific role in quantum light generation are discussed. Chapter 8 is dedicated to the interaction of the electronic excitations with phonons and possible electric and magnetic field fluctuations. These interactions lead to dephasing, spectral diffusion, and therefore to linewidth broadening, which can seriously impact the quality of quantum light. In Chapter 9, several reversible and permanent techniques for tuning the electronic and optical properties of QDs are presented, including temperature, electric and magnetic fields, and strain. Chapter 10 gives an overview of different optical and electrical excitations schemes and discusses their pro and cons. Finally, Chapter 11 is dedicated to an extensive discussion on the photon indistinguishability. We will discuss two-photon interference experiments of two different types, i. e., for photons originating from one and the same source and from two remote sources.

Part III (Chapters 12–14) is devoted to quantum-dot-related technologies and their devices. First, in Chapter 12, the most commonly utilized nanofabrication techniques are discussed, from semiconductor growth to lithography and etching. Particular care will be given to the so-called deterministic lithography approaches, which play a central role in the realization of high-performance quantum light sources. Chapter 13 provides a detailed overview of the photonic structures, which can be utilized for enhancing the light extraction and modifying the emission properties, such as the lifetime. The most common experimental approaches for the characterization of the key properties are also presented. The last chapter goes into the details of single- and entangled photon sources, their operation, design, and achievable performances, in particular, when coming to photonic quantum devices. Finally, photonic integrated circuits are discussed with focus on the main components required for on-chip quantum operations as linear quantum computing.

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