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Lateral Alignment of Epitaxial Quantum Dots

外延量子点的侧向排列

（影印版）

〔德〕施密特（O. G. Schmidt）主编

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序　言

物理学是研究物质、能量以及它们之间相互作用的科学。她不仅是化学、生命、材料、信息、能源和环境等相关学科的基础，同时还是许多新兴学科和交叉学科的前沿。在科技发展日新月异和国际竞争日趋激烈的今天，物理学不仅囿于基础科学和技术应用研究的范畴，而且在社会发展与人类进步的历史进程中发挥着越来越关键的作用。

我们欣喜地看到，改革开放三十多年来，随着中国政治、经济、教育、文化等领域各项事业的持续稳定发展，我国物理学取得了跨越式的进步，做出了很多为世界瞩目的研究成果。今日的中国物理正在经历一个历史上少有的黄金时代。

在我国物理学科快速发展的背景下，近年来物理学相关书籍也呈现百花齐放的良好态势，在知识传承、学术交流、人才培养等方面发挥着无可替代的作用。从另一方面看，尽管国内各出版社相继推出了一些质量很高的物理教材和图书，但系统总结物理学各门类知识和发展，深入浅出地介绍其与现代科学技术之间的渊源，并针对不同层次的读者提供有价值的教材和研究参考，仍是我国科学传播与出版界面临的一个极富挑战性的课题。

为有力推动我国物理学研究、加快相关学科的建设与发展，特别是展现近年来中国物理学者的研究水平和成果，北京大学出版社在国家出版基金的支持下推出了“中外物理学精品书系”，试图对以上难题进行大胆的尝试和探索。该书系编委会集结了数十位来自内地和香港顶尖高校及科研院所的知名专家学者。他们都是目前该领域十分活跃的专家，确保了整套丛书的权威性和前瞻性。

这套书系内容丰富，涵盖面广，可读性强，其中既有对我国传统物理学发展的梳理和总结，也有对正在蓬勃发展的物理学前沿的全面展示；既引进和介绍了世界物理学研究的发展动态，也面向国际主流领域传播中国物理的优秀专著。可以说，“中外物理学精品书系”力图完整呈现近现代世界和中国物理

科学发展的全貌，是一部目前国内为数不多的兼具学术价值和阅读乐趣的经典物理丛书。

“中外物理学精品书系”另一个突出特点是，在把西方物理的精华要义“请进来”的同时，也将我国近现代物理的优秀成果“送出去”。物理学科在世界范围内的重要性不言而喻，引进和翻译世界物理的经典著作和前沿动态，可以满足当前国内物理教学和科研工作的迫切需求。另一方面，改革开放几十年来，我国的物理学研究取得了长足发展，一大批具有较高学术价值的著作相继问世。这套丛书首次将一些中国物理学者的优秀论著以英文版的形式直接推向国际相关研究的主流领域，使世界对中国物理学的过去和现状有更多的深入了解，不仅充分展示出中国物理学研究和积累的“硬实力”，也向世界主动传播我国科技文化领域不断创新的“软实力”，对全面提升中国科学、教育和文化领域的国际形象起到重要的促进作用。

值得一提的是，“中外物理学精品书系”还对中国近现代物理学科的经典著作进行了全面收录。20 世纪以来，中国物理界诞生了很多经典作品，但当时大都分散出版，如今很多代表性的作品已经淹没在浩瀚的图书海洋中，读者们对这些论著也都是“只闻其声，未见其真”。该书系的编者们在这方面下了很大工夫，对中国物理学科不同时期、不同分支的经典著作进行了系统的整理和收录。这项工作具有非常重要的学术意义和社会价值，不仅可以很好地保护和传承我国物理学的经典文献，充分发挥其应有的传世育人的作用，更能使广大物理学人和青年学子切身体会我国物理学研究的发展脉络和优良传统，真正领悟到老一辈科学家严谨求实、追求卓越、博大精深的治学之美。

温家宝总理在 2006 年中国科学技术大会上指出，“加强基础研究是提升国家创新能力、积累智力资本的重要途径，是我国跻身世界科技强国的必要条件”。中国的发展在于创新，而基础研究正是一切创新的根本和源泉。我相信，这套“中外物理学精品书系”的出版，不仅可以使所有热爱和研究物理学的人们从中获取思维的启迪、智力的挑战和阅读的乐趣，也将进一步推动其他相关基础科学更好更快地发展，为我国今后的科技创新和社会进步做出应有的贡献。

“中外物理学精品书系”编委会 主任

中国科学院院士，北京大学教授

王恩哥

2010 年 5 月于燕园

Oliver G. Schmidt

Lateral Alignment of Epitaxial Quantum Dots

With 446 Figures

Springer

Introduction

The unique success story of semiconductor physics and technology relies on the ability to highly integrate micro- and nanometer sized functional units on a single chip. Within the last years epitaxial quantum dots have become such functional units and moved to the forefront of cutting edge research to study the exciting physics of single quantum structures and to fathom their tremendous potential for device applications.

Quantum dots constitute a natural template to construct refined artificial matter, such as artificial atoms, molecules and possibly artificial crystals with entirely new electronic and optical properties. However, the full advantage of their unique properties can be exploited, only, if a controlled positioning or growth of the quantum dots inside a more complex device structure or a precise coupling between the quantum dots and a macroscopic periphery can be achieved. The prime task of this book is to review recent techniques, which allow the controlled positioning and lateral alignment of quantum dots on standard substrate surfaces.

The alignment techniques range from pure self-ordering mechanisms to advanced quantum dot growth on patterned substrates. In the former case, growth conditions, substrate orientations and layer sequences are optimized to achieve a high degree of lateral ordering. In the latter case, the nucleation centers of the quantum dots are defined by appropriate pre-patterning of the substrate surfaces. This approach allows for an absolute positioning of the quantum dots relative to marker structures, which are necessary to define a device at the position of the quantum dot in subsequent processing steps.

While this book clearly documents the great advance made in controlling the spatial position of quantum dots, there remain huge challenges that need rigorous tackling in future years. One of the biggest problems is the non-resonant energy spectrum of quantum dot ensembles, even if they are located in an apparently perfectly ordered array. The reason is that each quantum dot is slightly different in size, shape and composition and therefore emits a photon with a different energy. The question of "How identical are nanostructures and can we create identical nanostructures?" addresses many fields of today's integrative nanotechnologies and is not inherent to quantum dots. For quantum dots, a solution might be a self-limiting growth mechanism or the manipulation of individual quantum dots after growth.

Part I of this book concentrates on the lateral self-alignment of epitaxial quantum dots. This self-alignment is realized by choosing appropriate growth conditions and special substrate surfaces. The self-alignment on a short range scale is exploited to create compact lateral quantum dot molecules. By stacking multiple quantum dot layers pronounced lateral ordering on a medium range scale is accomplished. The underlying growth mechanisms governing these phenomena are described and reviewed in detail in the first part of the book.

In the second Part the aim is to control the absolute lateral position of quantum dots on a long-range scale. Such long-range ordered quantum dot arrays might be useful for a high integration of single quantum dot devices, or to realize one, two, and three dimensional quantum dot crystals. Part II demonstrates that such artificial crystals can be created with high structural integrity and excellent optical quality. However, at the present stage the distances between quantum dots are too large as to observe new electronic band structures.

My gratitude goes to all authors having composed the 26 chapters of this book. It took more than two years to put together this work, but I am sure the effort was worthwhile and the book will serve as a helpful platform to understand the many fundamental questions of quantum dot growth as well as to further our efforts to eventually integrate single quantum dots on a single chip.

Oliver G. Schmidt

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