Chapter 1

Introduction

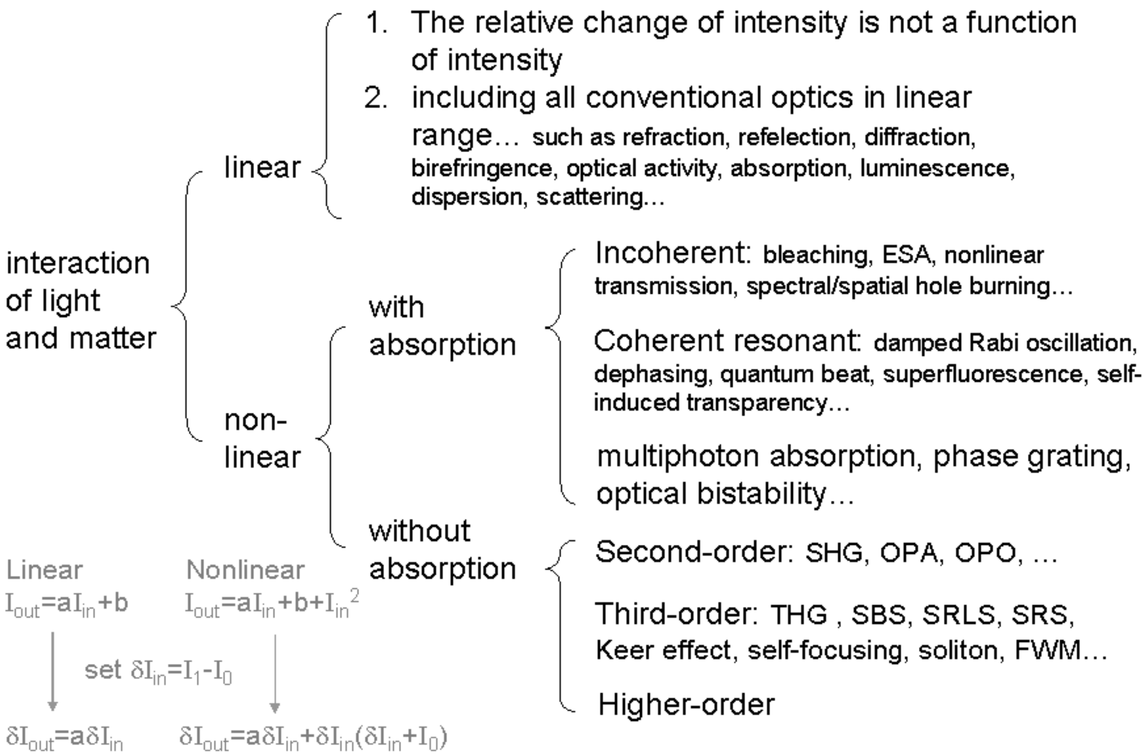

Fig. 1.1. Classification of "linear" and "nonlinear" interaction [B1]: the difference between them is if the relative change of intensity after the interaction (δI_{out}) is a function of intensity (I_{in}) or not. In fact, many effects could be linear or nonlinear, which depends on the intensity. Laser itself is the most obvious example of nonlinear interaction. Further, this thesis is intended to as an investigation of nonlinear interactions of laser light and matter inside laser cavities

1.1 Background

Interactions of light and matter have been occupying an important position in modern science whether people study the interaction itself, use it to explore the nature of material and unknown world, or put it in our life. Since lasers invented in 1960 [1], the special characters in progress such as high brightness, high coherence, narrow bandwidth, short pulsewidth, strong field, polarization…etc. have made the amount of researches and applications growing up more rapidly. Laser light, especially the nonlinear effects of and from it, expands research scope on science, technology, and medicine.

Generally speaking, research about laser falls into two categories: one is to utilize laser as a light source to probe science phenomena; the other one is to study how to produce laser we need, to ameliorate performance of laser, or to investigate mechanism and physics of laser. Most of our works are belong to the latter. However, there is higher brightness, stronger field, and more wonder inside laser cavities. With designed setup and confinement, and controlled condition, to study science phenomena inside laser cavity would provide better experimental conditions and new discoveries. Further, doing research inside laser system with high coherence might help other physical subjects in the future whether theories or experiments.

The structure of this thesis was based on that technical principle of experiment in the classification of nonlinear interaction [B1]. The author put main text in five chapters divided into two parts. In Part A, we are concerned with nonlinear absorption, bleaching, and emission in semiconductor which used as a saturable absorber or a gain medium in optical pumped solid-state laser. In Part B, we deal with interactions without absorption for applicable laser and the study of wave function. Chapters or sections in the thesis can be independent topics, and also have their own achievements presented on journals. But while different experiments were still progressing, more and more interesting physics was uncovered in different experiment system.

All physics should be connected or sing in tune if we could have thorough understanding. Through various experiment systems, we may see the face of physics from various viewpoints. What we present here is the research on intracavity nonlinear interactions of laser light and matter, from studying and understanding existing laser system and nonlinear effects to be the groundwork of thorough understanding hereafter.

1.2 Diode-Pumped Solid-State Lasers [B2,B3]

Solid-state laser means that gain media is solid-state material such as crystals, glasses or fibers doped with rare-earth transition-metal ions, and the semiconductor. Although semiconductor lasers (most of them are laser diodes pumped by electrons) and fiber lasers were not meant with the term solid-state lasers traditionally, they still belong to solid-state laser definitely. Today three practical pump sources are flash lamps, cw arc lamps, and laser diodes. These sources cooperate with three typical pump transfer methods: side-pumping, end-pumping, or face-pumping. The development and key parameters of solid-state lasers can be found on [B4: pp.1-11].

With the rapidly rising of a new star, diode-pumped solid-state laser (DPSSL or all-solid-state laser), the market of solid-state laser transcended it of CO_2 laser and became the most one in global laser market in 1998 [2]. DPSSLs with the advantages of relatively compact size, high power, excellent beam quality, long lifetime, and low heat production have been widely used for various applications including industry, pure science, medical diagnostics, military, and entertainment [3, 4]. DPSSLs not only have turned into important tools and brought huge amount of applications. Author's group member have been thinking that DPSSL may be relatively easier experiment or contrast system for the researches on mesoscopic optics, quantum-classical correspondence, quantum chaos, polariton, exiton, Bose-Einstein condensation, superconductor, and superfluid.

1.3 Guide to the Main Text

The most important content in each chapter was sketchily pointed out here.

First in Chapter 2 in Part A, we report that a low-loss semiconductor saturable absorber based on InAs/GaAs for applications on passively Q-switched, Q-switched mode-locked and continuous mode-locked lasers. We firstly talk about the important device, SESAM, before we demonstrate the first diode-pumped passively Q-switched and continuous mode-locked Nd-doped laser near 1.3 μm by use of InAs/GaAs quantum-dot built up during whole 2004.

However, the shallow modulation depth of quantum-dot SESAM is unfavorable to increasing pulse energy and peak power of Q-switched laser. It is still need another approach for passively Q-switching at 1.3 μm. So that we demonstrate the first use of InGaAsP quantum wells as a saturable absorber in the Q-switching of a diode-pumped Nd-doped 1.3-μm laser. Compare to quantum-dot saturable absorber it substantially increase the modulation depth for passively Q-switching at 1.3 μm. Then, we'll introduce semiconductor saturable absorber based on InGaAs/GaAs quantum wells that have been successfully developed for mode-locking or Q-switching of diode-pumped Nd-doped lasers operating around 1.1 to 1.3 μm. The Chapter 3 starts from the use of optoelectronic semiconductor materials in recent years: InGaAs/GaAs, InGaAsN/GaAs, InAn/GaAs, InGaAsP/InP, and AlGaInAs/InP.

Next, the booming laser techniques named VECSEL combine the flexibility of semiconductor band structure and advantages of solid-state laser such as beam quality, intracavity techniques… etc. In general, the wafer must be under low temperature with best heat spreader to reach high output power. But it is more practical if laser can be operated under room temperature. So we chiefly demonstrate a room-temperature high-peak-power nanosecond AlGaInAs 1.36-μm TEM_{00} laser pumped by a diode-pumped actively Q-witched Nd:YAG 1.06-μm laser.

Then we move to Part B, nonlinear interaction without absorption.

There are more interesting research topics and techniques than what is well known in application of intracavity second-order effects. Harmonic generation and phase matching had been applied on frequency conversion in many fields for industry and research. In addition to frequency-doubled high-peak-power pulse laser, noncollinear second harmonic generation of laser in random domain structures can be used to explore the spatial structure of two-dimensional disordered wave functions with weak localization. The statistics of the experimental near-field patterns agree very well with the theoretical distributions. This result and other studies in the experiment also confirm the possibility of using conical second harmonic generation as a diagnostic tool for topographical characterization of crystals. There is one other topic that is important in second-order nonlinear effect, optical parametric amplifier and oscillator. Through the techniques of optical parametric oscillator with shared cavity and diode stack pumping, we are studying the eye-safe laser with high pulse energy for modern military requirement. In Chapter 5, although more pages used than other chapters, there is still plenty real meat that needs to study and confirm.

It is the Chapter 6, where we focus attention on Raman laser applying the stimulated Raman scattering, one of the third-order nonlinear effects. We show the study of $Nd:YVO_4$ intracavity self-Raman laser and the possible solution to improve damage threshold. Following that, we demonstrate a $Nd:YAG/BaWO_4$ Raman laser with highest efficiency till then by the first use of actively Q-switching.

Finally, from our works, we summarize the sentiments including more possible physics behind phenomena, and the achievements on laser engineering and physics. Furthermore, we show other topics what we are going to research into about the intracavity nonlinear interactions of laser and matter.