PREFACE

The word “chaos” has become very popular nowadays. In electrical circuits, chemical reactions, laser systems every where we can find chaos. There is chaos within our body itself. The biological signals within our body can become chaotic at times. Unpredictability which is the main characteristic feature of chaos is everywhere. In nature the climate changes can become unpredictable. Sometimes spreading of a disease and population growth may go beyond our calculations. Since last century scientists are trying to unravel the mysteries behind chaos. They defined a chaotic system as one whose dynamics is complex and at the same time governed by deterministic evolution equations. The most important characteristic property of a chaotic system is found to be its sensitive dependence on initial conditions. Several roots to chaos are found and various quantitative and qualitative measures of chaos are introduced.

It seems quite amazing that we can make two chaotic systems behave in the same manner or make them synchronize with each other. Synchronization of chaotic lasers has gained great importance as a means to generate high power laser sources. Efficient communication systems are devised based on the synchronization property of chaotic semiconductor lasers. Recently it has been shown that multimode lasers have many advantages over single mode lasers. Therefore novel high quality communication systems have been developed using multimode Nd:YAG lasers.

Another related area which needs special attention is control of chaos. Introduction of a delay feedback is found to be an efficient method for controlling chaos in various laser systems. Semi conductor lasers and Nd:YAG lasers are found to exhibit interesting phenomena like hysteresis
and multistability. Multistability is also found to occur in various biological systems. Availability of good and fast computational tools and easily accessible control parameters make the laser systems good candidates as model systems for studying these phenomena.

Nonlinear dynamics of multimode Nd:YAG lasers is the central theme of this thesis. We discuss the synchronization of chaotic Nd:YAG lasers under various coupling schemes, Hopf bifurcation phenomena exhibited by the laser under the variation of a particular control parameter and also the delay induced multistability in the laser system. The thesis is divided into seven chapters.

Chapter 1 gives an introduction to chaos. Chaos in various dynamical systems is discussed briefly giving special concern to lasers. The characteristic features of a chaotic system are identified. Different tools for measuring chaos, routes to chaos undertaken by dynamical systems are also described. Hopf bifurcation phenomena and period doubling route to chaos are discussed in detail taking Rossler system and van der Pol oscillator as examples. There is also discussion about the origin of chaos in laser systems especially in semiconductor and Nd:YAG lasers.

The concept of synchronization is introduced in Chapter 2. There is discussion about various coupling schemes used for achieving synchronization. Different types of synchronization in dynamical systems such as generalized synchronization, phase synchronization, lag synchronization and complete synchronization are explained. We take Rossler oscillator as a model system to study phase and lag synchronization. Synchronization phenomena exhibited by various dynamical systems
especially lasers are discussed. The importance of controlling chaos and various chaos controlling schemes are also described briefly in this chapter.

In Chapter 3, there is description of our model system used for numerical studies which is an Nd:YAG laser with intracavity KTP crystal. Origin of chaotic intensity fluctuations in this laser is discussed. There is detailed description of laser dynamics based on a rate equation model. Lasers with two mode and three mode output are studied separately. Time series plots, phase space plots and bifurcation diagrams are used to get a clear picture about the laser dynamics. The reverse period doubling route from chaos to stability exhibited by the laser as the orientation of the YAG rod and KTP crystal is varied is also studied.

In Chapter 4 we present the results of our numerical studies on synchronization and control of chaos in coupled chaotic multimode Nd:YAG lasers. Effect of unidirectional and bidirectional couplings on the dynamics of Nd:YAG lasers having two mode and three mode output are studied. Lasers are coupled via external electronic coupling in which pumping of each laser is modulated according to the output intensity of the other. Unidirectional and bidirectional coupling schemes are adopted. It is found that bidirectional direct coupling scheme is effective in achieving control of chaos, synchronization and amplification in output intensity for lasers with two mode output. With bidirectional difference coupling the lasers remain chaotic for the entire range of coupling strength without any amplification or synchronization in output intensity. Lasers are found to exhibit phase synchronization under unidirectional direct coupling at higher coupling strengths. Unidirectional difference coupling can only produce amplification in output intensity for the second laser without any synchronization between
them. In the case of lasers having three mode output, bidirectional difference coupling can give synchronization of higher quality as compared to unidirectional difference coupling, only at the cost of higher coupling strength.

In Chapter 5 we are presenting an analytical and numerical treatment of the dynamics of Nd:YAG laser operating with two modes having parallel polarization. System fixed points are found out analytically. It is found that the system has got nine fixed points out of which only three are having real values. In order to check the stability of these three fixed points, we use Routh-Hurwitz criteria and also the method of eigen values. It is found that one fixed point loses stability at a particular value of the control parameter and evolves as a limit cycle through Hopf bifurcation. The other two fixed points remain unstable throughout the entire region of the control parameter. Change in sign of the Routh Hurwitz coefficients and the real part of eigen values confirm our result. Hopf bifurcation phenomena exhibited by Nd:YAG laser is studied numerically also. Effect of change in control parameter on the energy transfer between the two modes is also investigated.

Chapter 6 deals with the dynamics of Nd:YAG laser under a delay feedback. An optoelectronic delay feedback is given to an Nd:YAG laser operating in the limit cycle region and its dynamics is studied. Both positive and negative feedback cases are studied separately. Laser with positive feedback is found to exhibit rich dynamics as compared to that with negative feedback. We mainly use bifurcation diagrams to study the laser dynamics. Lasers with positive feedback exhibit quasiperiodicity, period doubling and chaos with increase of delay time. We use power spectra and intensity peak series plots to characterize various regions in the output. Existence of chaotic
region is confirmed with a positive Lyapunov exponent and a fractional correlation dimension. Laser is found to exhibit multistability and hysteresis for certain delay times. One interesting result in the delay feedback studies is the coexistence of chaotic and quasiperiodic regions in the laser output at a particular value of the delay under positive feedback. Chaotic windows are found to occur in a regular fashion as the delay is increased. As the feedback fraction is increased the laser output intensity also increases.

With negative feedback, a sudden jump into chaotic region is observed at smaller delays. Chaotic and periodic regions occur alternately as the delay is increased. The frequency with which the chaotic region appears increases as the delay is increased while the peak intensity value of the chaotic regions decreases. At higher feedback fractions also the laser output intensity undergoes a sudden jump into the chaotic region. The output remains chaotic for higher delays.

Summary and conclusions of our work are given in Chapter 7. Some possible works in this field are also discussed.