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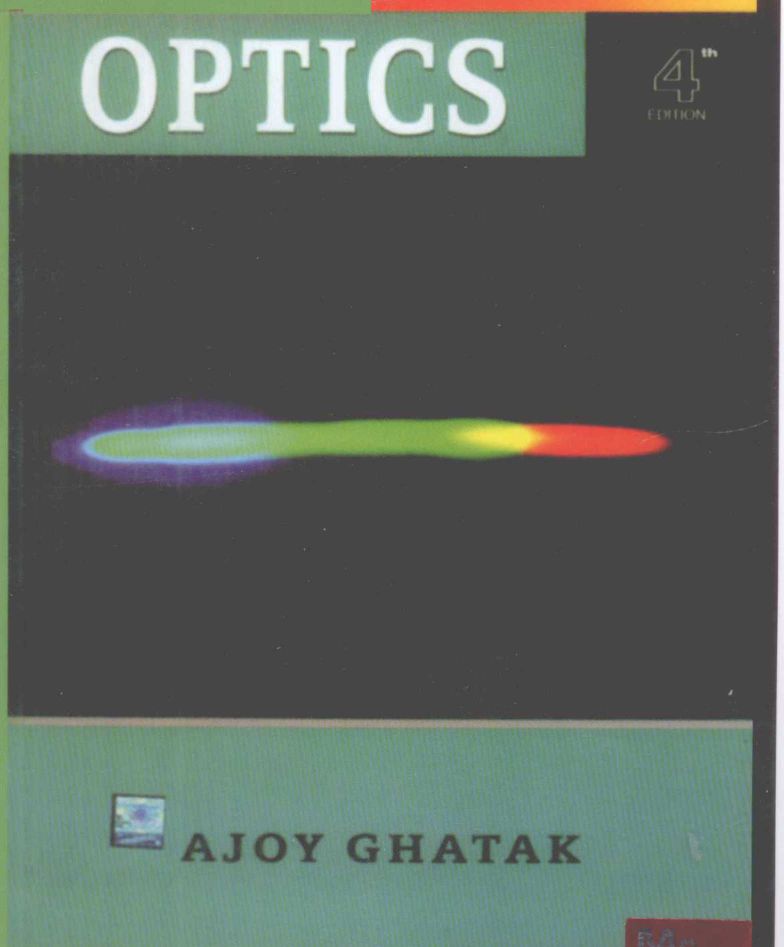
国际著名物理图书——影印版系列

AJOY GHATAK

光学（第4版）



清华大学出版社

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Optigs
(Fourth Edition)

AJOY GHATAK

清华大学出版社
北京

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OPTICS, 4^{th} EDITION

影 印 版 序

2009 年是光信息科学与技术领域的所有科技工作者印象深刻的一年，这一年的诺贝尔物理学奖花落光信息科学与技术的先行者。华裔科学家、光纤之父高锟因他在 1966 年提出光纤损耗机理的工作，美国科学家 Willard S. Boyle 和 E. Smith 以在 1977 年发明 CCD（电荷耦合器件）的工作，共同获得 2009 年度的诺贝尔物理学奖。他们先驱性的工作为今天信息化、网络化的社会生活奠定了基础。他们的获奖激励着光信息科学与技术领域的科学工作者再接再厉，把光信息科学与技术推向更高的层次；同时也鼓励更多的年轻人立志投身于本领域的研发工作；即使对于普通群众，借助于网络与媒体，也感受到了“光”的美妙。

在这一时刻，清华大学出版社着手影印出版著名光学专家 Ajoy Ghatak 所著《光学（第 4 版）》正当其时。一来为国内广大光信息科学与技术科学工作者提供本领域的基础教材；二来为配合落实教育部倡导的双语教学提供了一本精品教材。

Ajoy Ghatak 是印度德里理工大学物理系教授，在光学、光纤光学和量子力学领域著述颇丰。著有 *Optics*, 4/e，*An Introduction to Fiber Optics*，*Lasers Theory and Applications*，*Contemporary Optics*，*Fiber Optics and Lasers*: *The Two Revolutions*，*Introduction to Quantum Mechanics*，*Quantum Mechanics*: *Theory and Applications*, 5/e，*Mathematical Physics*: *Differential Equations and Transform Theory*，*Special Theory of Relativity* 等。其中 *Optics* 第 1 版（1977）与 *Contemporary Optics*（1978）已有中译本。

目前在西方大学最流行的基础光学教材有 Adelphi University 的 Eugene Hecht 教授所著 *Optics*（目前已出第 6 版）与 Ajoy Ghatak 教授所著 *Optics*（目前为第 4 版）。在二者当中，笔者认为后者从写作内容到编排顺序与国内基础光学教材更为接近，比较符合国内基础光学的教学习惯，因此作为基础光学的双语教材更为合适。

本书分为 7 部分，分别是几何光学、振动与波、干涉、衍射、光的电磁特性、光子、激光与纤维光学。笔者总结本书的特色如下：

- 本书的主要传统内容——几何光学、振动与波、干涉、衍射、偏振等的安排与国内一般光学教材的顺序一致，与国内习惯了的光学课程的教学计划不冲突，使教师不必因为教材不同而修改教学计划。
- 本书不仅系统地介绍了光学知识，还为读者提供了许多光学发展背景。像第一章光学史是每本光学教材开篇必备的，而本书是笔者所见过各种教材中对于光学发展历史介绍得最精彩、最丰富的范例之一。本书从早在公元前 400 年提出视觉是来源于从眼睛中发出的看不见的“火”遇到物体后产生效应的古希腊哲学家阿尔希塔斯开始，一直介绍到 1987 年发明掺铒光纤放大器的佩恩教授，其中还有光纤

之父、华裔科学家高锟教授。以这些科学家对于光学的贡献为线索，介绍光学的发展史，生动有趣。另外，在许多章的开篇，都有一个与该章内容相关的重要发展里程碑列表。让读者学习相关知识之前，对相关发展历史有一个概览。

- 本书不仅包括传统光学教材的内容（如几何光学、干涉、衍射、偏振等），还增加了许多新内容，以体现近代光学的发展。特别是体现了近50年来信息光学的大发展，如光纤通信（第27、28、29章）、周期性光学结构（第15章）、光学存储（第18章）等。
- 每部分最后都安排了非常全面的小结，使读者在一阶段的学习之后，查漏补缺，有利于巩固已学的知识。
- 本书将光学的理论系统介绍与这些理论对于自然现象的解释和在工程实际的应用进行了有机的结合。使读者不仅掌握了精彩的光学基础知识，还见识到了这些理论如何解释日常生活中的一些自然现象；最重要的是学到了如何将基础知识运用到工程技术中去的科学思路。例如在3.1节介绍了费马原理以后，在3.3.1节中，就用该原理解释了海市蜃楼现象；在7.5节介绍了折射率起源的理论后，紧接着在7.6节通过瑞利散射解释了天空为什么呈现蓝色；在15.2节阐述薄膜干涉的原理后，在15.6节通过介绍光学周期性结构过渡到光纤布拉格光栅的工作原理，并介绍了布拉格光栅作为光学传感器的应用；第18章在系统阐述了衍射原理后，知道了衍射分辨本领与光波长成反比，在18.12节马上介绍了CD光盘与DVD光盘在激光读写时，所用激光器分别为红外780nm和红光650nm的原因，并介绍了蓝光（405nm）DVD；……特别值得一提的是，在第3章中将3.1节的费马原理与3.4节光线方程的内容相结合，然后在27.10节用抛物线渐变折射率多模光纤模式色散的计算再次呼应了第3章的理论。体现了作者在内容安排上的独具匠心，也让读者领会到古老的费马原理在渐变折射率多模光纤中的具体应用。

鉴于上述对Ajoy Ghatak教授学术的背景介绍、以及对本教材特色的分析，笔者推荐本教材的影印版在各大学本科的物理、应用物理、光信息科学与技术等专业的光学课程与光学双语教学课程中，作为双语教材或参考教材使用，并推荐该教材作为广大相关领域的科学工作者与技术人员的参考书。

张晓光
北京邮电大学信息光子学与光通信研究院
2010年2月

OPTICS
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Fig. 3 (also Fig. 3.17) *Miraged image of the Sun:* the photographs were taken by Dr George Kaplan of the U. S. Naval Observatory and are on the website http://mintaka.sdsu.edu/GF/explain/simulations/infmir/Kaplan_photos.html created by Dr A. Young; photographs used with permissions from Dr Kaplan and Dr Young.

Fig. 4 (also Fig. 3.16) *A typical mirage*: the photograph was taken by Professor Piotr Pieranski of Pozn University of Technology in Poland; used with permission from Professor Pieranski.

Fig. 6 (also Fig. 3.20) *On superior mirage*: the photograph was taken by Dr Pekka Parviainen in Turku, Finland; used with permission from Dr Parviainen.

Fig. 8 *On the setting sun*: the photograph was taken by Dr William Biscorner; used with permission from Dr Biscorner.

Fig. 11 *On scattering of light*: the photograph was taken by Mr Marshall Dudley; used with permission from Mr Dudley.

Fig. 14 (also Fig. 15.8) *On anti-reflective coatings:* the photograph was taken by Mr Justin Lebar; used with permission from Mr Lebar.

Fig. 20 (also Fig. 18.24) *Image of the binary star Zeta Bootis*: the photograph was taken by Dr Bob Tubbs; used with permission from Dr Tubbs.

Fig. 27 (also Fig. 22.10) *Sunlight reflected at near Brewster's angle:* the photograph was taken by Dr J Alcoz; used with permission from Dr Alcoz.

Fig. 28 (also Fig. 22.11) *On polarization by reflection*: the photographs were taken by Dr J Alcoz; used with permission from Dr Alcoz.

Fig. 39 (also Fig. 26.22) *Helium Neon laser*: photograph by Dr David Monniaux; used with permission from Dr Monniaux.

PREFACE TO THE FOURTH EDITION

The first laser was fabricated in 1960, and since then there has been a renaissance in the field of optics. From optical amplifiers to laser physics, fiber optics to optical communications, optical data processing to holography, optical sensors to DVD technology, ultra-short pulse generation to super continuum generation, optics now finds important applications in almost all branches of science and engineering. In addition to numerous practical applications of optics, it is said that it was the quest to understand the 'nature of light' that had brought about the two revolutions in science: the development of quantum mechanics started with an attempt to understand the 'light quanta' and the starting point of the special theory of relativity was Maxwell's equations which synthesized the laws of electricity and magnetism with that of light. Because of all this, an undergraduate course in optics has become a 'must' not only for students of physics but of engineering as well. Although it is impossible to cover all areas in one single book, this book attempts to give a comprehensive account of a large number of important topics in this exciting field and should meet the requirements of a course on optics meant for undergraduate students of science and engineering.

The first edition of this book appeared in 1977 and it is indeed a matter of great satisfaction that during the past 31 years, the book has been received well by the academic community in India; the first edition also got translated into Chinese and Persian and the third edition got reprinted in Singapore. I have myself used this book several times in teaching the undergraduate course on Optics to engineering students as well as to students of Engineering Physics at IIT, Delhi and have felt the necessity of rewriting certain portions of the book. Thus, while preparing the present edition of the book, extensive revisions have been made — a few chapters have been added and a number of new topics have been introduced.

New to the Edition

A summary of changes in the content of the book are given below.

- The book now starts with a large number of coloured photographs portraying interesting topics in Optics and a new chapter (Chapter 1 on *History of Optics*) that tracks the evolution of this subject.
- Significant revisions made in Chapter 2 on *What is Light* and new figures integrated in Chapter 3 on *Fermat's Principle and its Application* make the presentation more clear.
- Chapter 9 on *Dirac Delta Function and Fourier Transform* is a new chapter that covers representations of the Dirac delta function, Fourier integral theorem, and two and three dimensional Fourier transforms; these are very important for understanding the field of Fourier Optics.
- In Chapter 15 on *Interference by Division of Amplitude,* figures have been replaced and the section on Fiber Bragg Gratings has been rewritten. Chapter 18 on *Fraunhofer Diffraction: I* has been rewritten with inclusion of new figures and Chapter 19 on *Fraunhofer Diffraction: II and Fourier Optics* is new to this edition.
- Chapter 22 on *Polarization and Double Refraction* and Chapter 25 on *The Particle Nature of Radiation* have been revised with addition of new figures.
- 10 additional figures for Chapter 26 on *Lasers: An Introduction* form the new highlights of this chapter.
- Chapters 27, 28 and 29 are three new chapters, written on fiber optics and waveguide theory — an area which has, during the last 35 years, revolutionized communications. These chapters focus on Basic Concepts and Ray Optics Considerations, Basic Waveguide Theory and Concept of Modes and Single Mode Fibers.

I may mention that my own research interests are in the general area of fiber optics and I have found that there are many beautiful experiments in fiber optics (not very difficult to set up) which not only allow us to understand difficult concepts but they also find very important applications. For example, the working of a Fiber Bragg Grating is a striking application of the interference phenomenon and finds important applications in sensors and other optical devices. Similarly, the prism film coupling experiment allows us to understand the concept of quantization and the Faraday rotation in optical fibers finds important application in the industry. Further, an almost monochromatic laser pulse propagating through a special optical fiber can lead to the 'awesome' super-continuum generation. There are many such examples and in the revised edition, I have included some of them.

Organization of the Book

The book attempts to give a balanced account of traditional optics as well as some of the recent developments in this field. The plan of the book is as follows:

- Very often, a good photograph clarifies an important concept and also makes the student interested in the subject. It is with this intention that we have started the book with a few colored photographs that describe important concepts in optics.
- The first chapter of the book gives a brief history of the development of optics. I have always felt that one must have a perspective of the evolution of the subject that he (or she) wants to learn. Optics is such a vast area that it is extremely difficult to give a historical perspective of all the areas; as such, I may have missed names of persons who have made important contributions. Fortunately there is now a wealth of information available through the Internet; I have included a large number of references to various books and websites. I have highlighted the evolution of fiber optics and related areas, and the names of many individuals who have made important contributions to the growth of optics.
- The second chapter gives a brief historical evolution of different models describing the nature of light. It starts with the corpuscular model of light and then discusses the evolution of the wave model and the electromagnetic character of light waves. Then we have a discussion of the early twentieth century experiments, which could only be explained by assuming particle nature of light, and ends with a discussion as to how we reconcile to 'wave-particle duality'.
- Chapters 3 to 6 are on geometrical optics. Chapter 3 starts with Fermat's principle and discusses ray tracing through graded-index media explaining in detail the phenomena of mirage and looming, ray propagation through graded index optical waveguides and also reflection from the ionosphere. Chapter 4 is on ray tracing in lens systems and Chapter 5 is on the matrix method in paraxial optics, which is used in the industry. Chapter 6 gives a brief account of aberrations.
- Chapters 7 to 12 discuss the origin of refractive index and the basic physics of wave propagation including Huygens' principle. Many interesting experiments (like the redness of the setting sun, water waves, etc.) are discussed. The concept of group velocity and the dispersion of an optical pulse as it propagates through a dispersive medium have been discussed in detail. Self Phase Modulation (usually abbreviated as SPM), which is one of the phenomena leading to the super-continuum generation, has also been explained.
- Chapters 13 to 16 cover the very important and fascinating area of interference and many beautiful experiments associated with it – the underlying principle is the superposition principle, which is discussed in Chapter 13. Chapter 14 discusses interference by division of wave front including the famous Young's double hole interference experiment. In Chapter 15, interference by division of amplitude is discussed which allows us to understand colors of thin films and applications like non-reflecting films, etc. The basic principle of the working of the Fiber Bragg Gratings (usually abbreviated as FBG) is discussed along with some of its important applications in the industry. In the same chapter, Michelson Interferometer is also discussed which is *perhaps one of the most ingenious and sensational optical instrument* for which Michelson received the Nobel Prize in Physics in 1907. Chapter 16 discusses the Fabry – Perot interferometer that is based on multiple beam interference and is characterized by a high resolving power and hence finds applications in high-resolution spectroscopy.
- Chapter 17 discusses the basic concept of temporal and spatial coherence. The ingenious experiment of Michelson, which used the concept of spatial coherence to determine the angular diameter of stars, has been discussed in detail. Topics like optical beats and Fourier transform spectroscopy have also been discussed.
- Chapters 18, 19 and 20 cover the very important area of diffraction and discuss the principle behind topics like diffraction divergence of laser beams, resolving power of telescopes, laser focusing, X-ray diffraction, Fourier optics and spatial frequency filtering, etc.
- Chapter 21 is on holography giving the underlying principle and many applications. Dennis Gabor received the 1971 Nobel Prize in Physics for discovering the principle of holography.

- The next three chapters are on the electromagnetic character of light waves. Chapter 22 discusses the polarization phenomenon and propagation of electromagnetic waves in anisotropic media including first principle derivations of wave and ray velocities. Phenomena like optical activity and Faraday rotation (and its applications to measuring large currents) have been explained from first principles. In Chapter 23, starting with Maxwell's equations, the wave equation has been derived which had led Maxwell to predict the existence of electromagnetic waves and also to propound that light is an electromagnetic wave. Reflection and refraction of electromagnetic waves by a dielectric interface have been discussed in Chapter 24. Results derived in this chapter directly explain phenomena like Brewster's law, total internal reflection, evanescent waves, Fabry-Perot transmission resonances, etc.
- Chapter 25 is on the particle nature of radiation – for which Einstein received the 1921 Nobel Prize. The chapter also discusses the Compton Effect (for which Compton received the 1927 Nobel Prize in Physics), which established that the photon has a momentum equal to h/λ.
- Chapter 26 is on Lasers – a subject of tremendous technological importance. The basic physics of optical amplifiers and of lasers along with their special characteristics are also discussed.
- The last three chapters are on waveguide theory and Fiber Optics – an area that has revolutionized communications and find important applications in sensor technology. Chapter 27 discusses the light guidance property of the optical fiber (using ray optics) with applications in fiber optic communication systems. The chapter also gives a very brief account of fiber-optic sensors. Chapter 28 discusses basic waveguide theory with Maxwell's equations as the starting point. The last chapter discusses the propagation characteristics of single mode optical fibers, which are now extensively used in optical communication systems.

In summary, the book discusses some of the important topics that have made tremendous impact in the growth of science and technology.

Salient Features of the Book

- A large number of figures correspond to actual numerical calculations which were generated using software like GNUPLOT and Mathematica. There are also some diagrams which give a three dimensional perspective of the phenomenon.
- Every chapter starts with important milestones in the area. This would give a historical perspective of the topic.
- All important formulae have been derived from first principles so that the book can also be used for self study.
- Numerous worked out examples are scattered throughout the book, this should help clarify difficult concepts.
- Each chapter ends with a summary of important results derived in the chapter. Problems for practice reinforce understanding of concepts. Also, references and suggested readings give the reader leads to avail more information.
- Appendices include Gamma Functions and integrals involving Gaussian Functions, Diffraction of a Gaussian Beam and TE and TM modes in Planar Waveguides.

Explore the Web

A website accompanies this book to provide additional resources for learning and teaching. Supplements available in electronic form include articles on Optical Instruments for the students and Solution Manual and chapter wise PowerPoint Slides for the instructors.

I dedicate this book to my students: my continuous interactions with them have led to a deeper understanding of optics. I end with the quotation (which I found in a book by G.L. Squires): *I have learnt much from my teachers, but more from my pupils*. To all my pupils, I owe a very special debt.

I will be very grateful to receive suggestions for further improvement of the book. My email addresses are ajoykghatak@yahoo.com and ajoykghatak@gmail.com .

Acknowledgements

At IIT, Delhi, I was very fortunate to have the opportunity to interact with outstanding colleagues and students, which made teaching any course, a pleasure and a challenge. We had the opportunity and freedom to modify and develop any course and present it in a form, which would make the subject more interesting. That is how the present book has evolved.

In this evolution, many persons have assisted me and provided valuable comments. I would first like to mention the name of my very close friend and colleague, Professor Ishwar Goyal who had used earlier editions of this book many times while teaching Optics at IIT, Delhi and had made numerous suggestions and constructive criticisms. I am sure he would have been very happy to see the present edition of the book but unfortunately, he is no more with us – I greatly miss my interactions with him. I am also very grateful to Professor M.S. Sodha for his constant encouragement and support. I am indebted to Professor K. Thyagarajan for continuous collaboration and also for letting me use some of his unpublished notes. I would like to express my sincere thanks to Professor Arun Kumar, Professor Lalit Malhotra, Professor Bishnu Pal, Professor Anurag Sharma and Professor K. Thyagarajan (from IIT, Delhi); Dr Kamal Dasgupta and Dr Mrinmay Pal (from CGCRI, Kolkata); Dr Rajeev Jindal and Mr Giriraj Nyati (from Moser Baer in Noida); Professor Vengu Lakshminarayanan (from University of Waterloo, Canada) and Professor Enakshi Sharma (now at University of Delhi, South Campus) for their help in writing some portions of the book. My profound thanks to Dr Gouranga Bose and Dr Parthasarathi Palai (now at Tejas Networks in Bangalore), Professor Chandra Sakher, Professor R.S. Sirohi and Dr Ravi Varshney (from IIT, Delhi); Professor Govind Swarup (from GMRT, Pune); Dr Somnath Bandyopadhyay, Dr Shyamal Bhadra, Dr Kamal Dasgupta, Dr Tarun Gangopadhyay, Ms Atasi Pal and Dr Mrinmay Pal (from CGCRI, Kolkata); Dr Suresh Nair (from NeST, Cochin); Mr Avinash Pasricha (from the US Information Service at New Delhi); Professor Ajoy Kar and Dr Henry Bookey (from Heriot Watt University, Edinburgh); Dr R.W. Terhune, Professor R.A. Phillips and Dr A.G. Chynoweth (from USA) and Dr R.E. Bailey (from Australia) for providing me important photographs that I have used in this book. I thank Mr V.V. Bhat for providing me literature on the contributions made by scientists and technologists in ancient India. I would also like to express my gratitude to my other colleagues — Professor B.D. Gupta, Professor Ajit Kumar, Professor M.R. Shenoy and Professor Kehar Singh for collaboration in research and stimulating discussions. I also thank all the authors and their publishers for allowing me to use many diagrams from their published work.

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New Delhi
June 2008

Ajoy Ghatak

PHOTOGRAPHS

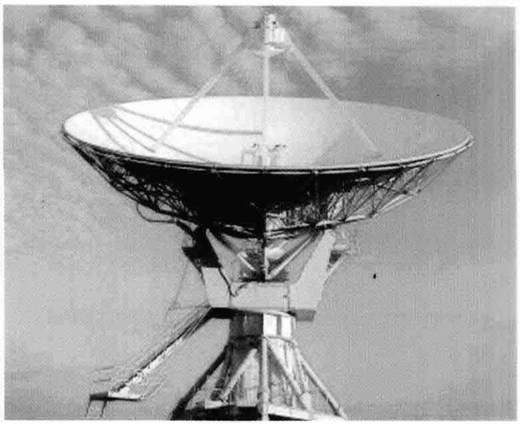

Fig. 1 A paraboloidal satellite dish.

[Photograph courtesy: McGraw-Hill Digital Access Library]

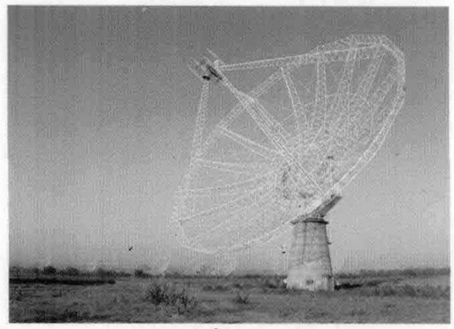

Fig. 2 Fully steerable 45m paraboloidal dishes of the Giant Metrewave Radio Telescope (GMRT) in Pune, India. The GMRT consists of 30 dishes of 45m diameter with 14 antennas in the Central Array.

[Photograph courtesy: Professor Govind Swarup, GMRT, Pune]

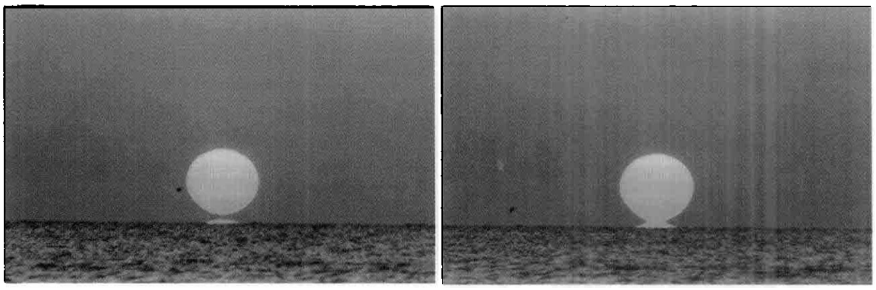

Fig. 3 This is actually *not* a reflection in the ocean, but the miraged (inverted) image of the Sun's lower edge. A few seconds later (notice the motion of the bird to the left of the Sun!), the reflection fuses with the erect image. The photographs were taken by Dr. George Kaplan of the U. S. Naval Observatory and are on the Naval Observatory's website.

[Figure adapted from http://mintaka.sdsu.edu/GF/explain/simulations/infmir/Kaplan_photos.html]

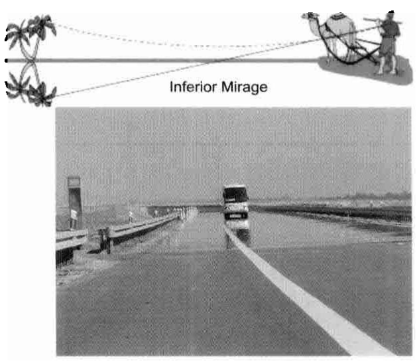

Fig. 4 A typical mirage as seen on a hot road on a warm day. *[Figure adapted from http://fizyka. phys.put.poznan.pl/~pieransk/Physics%20Around %20Us/Air%20mirror.jpg]*

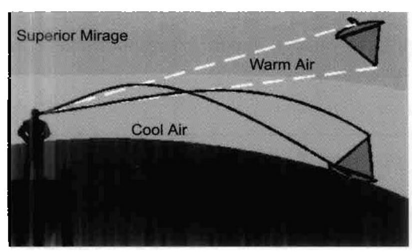

Fig. 5 The *superior mirage* occurs under reverse atmospheric conditions from the inferior mirage. For it to be seen, the air close to the surface must be much colder than the air above it. This condition is common over snow, ice and cold water surfaces. When very cold air lies below warm air, light rays are bent downward toward the surface, thus tricking our eyes into thinking an object is located higher or is taller in appearance than it actually is.

[Figure adapted from http://www.islandnet.com/~see/weather/elements/mirage1.htm]

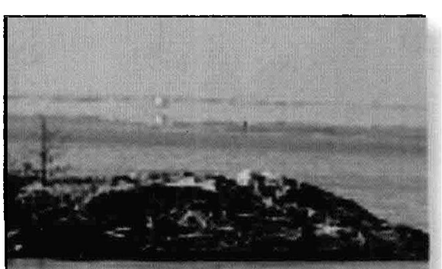

Fig. 6 A house in the archipelago with a superior mirage.

[Figure adapted from http://virtual.finland. fi/netcomm/news/showarticle.asp?intNWSAID= 25722]

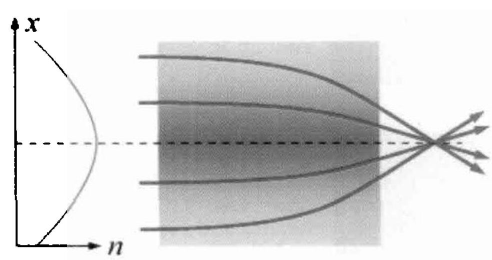

Fig. 7 A gradient-index lens with a parabolic variation of refractive index. The lens focuses light in a way similar to a conventional lens.

[Figure adapted from http://en.wikipedia.org/wiki/Refractive_index]

Fig. 8 The setting sun.

[Figure adapted from http://www.creations-photos.com/sunrise.html]

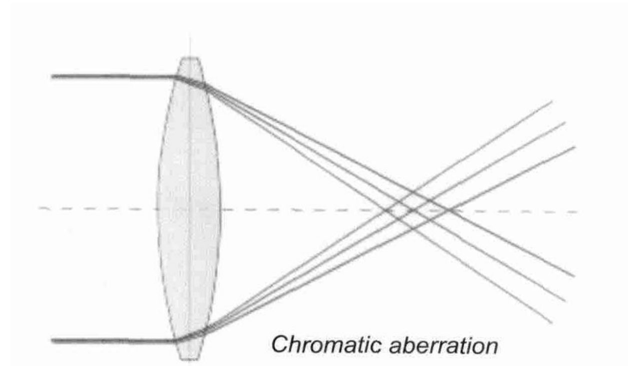

Fig. 9 Chromatic aberration of a single lens causes different wavelengths of light to have differing focal lengths.

[Figure adapted from http://en.wikipedia.org/wiki/Chromatic_aberration]

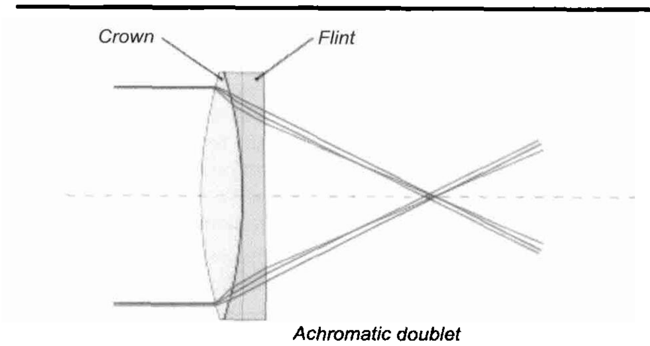

Fig. 10 For an achromatic doublet, visible wavelengths have approximately the same focal length.

[Figure adapted from http://en.wikipedia.org/wiki/Chromatic_aberration]

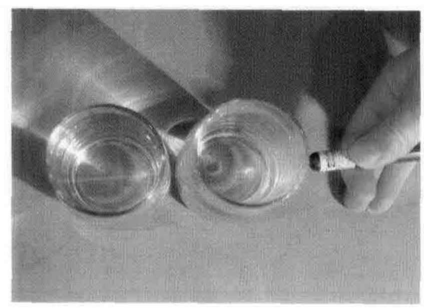

Fig. 11 On the right is a glass of distilled water and the left glass has a few drops of milk in it. Because of scattering, the laser beam can be easily seen as it travels through the liquid.

[Figure adapted from http://silver-lightning.com/tyndall/]

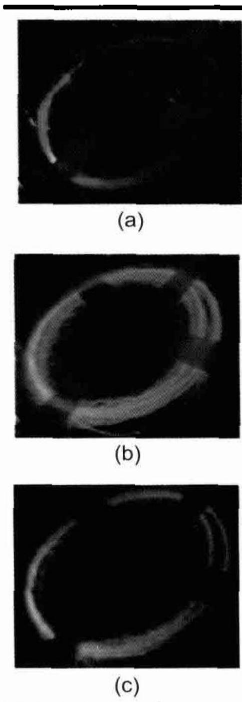

Fig. 12 Laser pulses of 80fs duration having a wavelength 800 nm are incident on a special optical fiber known as a photonic crystal fiber (PCF); these special fibers are characterized by very small mode field diameters which leads to very high intensities. Because of the high intensities, nonlinear effects like Self Phase Modulation (usually abbreviated as SPM and discussed in Sec. 10.4) can be observed which results in the generation of new frequencies. (a) corresponds to the pulse having a total energy of 0.09 nJ; the light coming out is due to Rayleigh scattering at the incident wavelength and the total energy in the pulse is not large enough to generate new frequencies. (b) and (c) corresponds to laser pulses of the same wavelength (= 800 nm) but now the incident pulse has an increased total energy of 1.5 nJ; because of the higher intensities, new frequencies are generated because of nonlinear effects. The special fiber was fabricated by Dr Shyamal Bhadra and his group at CGCRI, Kolkata and the generation of new frequencies was observed by Professor Ajoy Kar and Dr Henry Bookey at Heriot Watt University at Edinburgh.

Fig. 13 A pattern of coloured light formed by interference between white light being reflected from the surface of a thin film of diesel fuel on the surface of water, and the diesel-water interface; photo taken by Dr. Guinnog.

[Figure adapted from http:// en.wikipedia.org/wiki/Thin-film_optics]

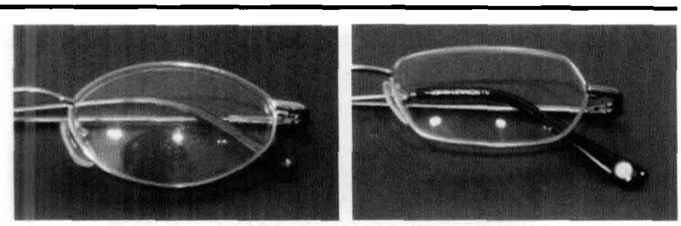

Fig. 14 Comparison between a glasses lens without anti-reflective coating (top) and a lens with anti-reflective coating (bottom). Note the reflection of the photographer in the top lens and the tinted reflection in the bottom.

[Figure adapted from http://en.wikipedia.org/wiki/Optical_coating (Photograph taken by Justin Lebar)]

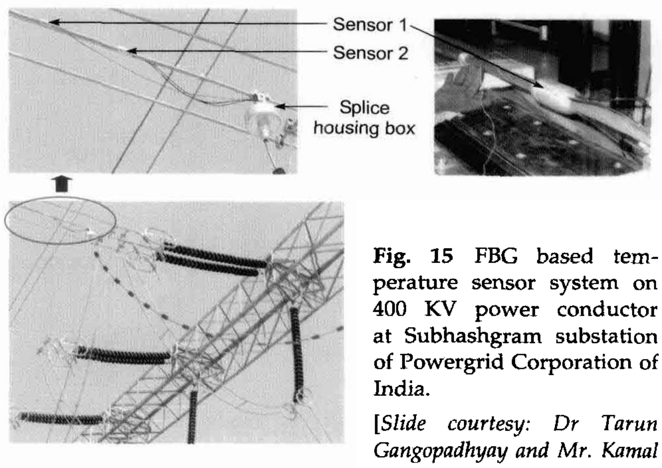

Fig. 15 FBG based temperature sensor system on 400 KV power conductor at Subhashgram substation of Powergrid Corporation of India.

[Slide courtesy: Dr Tarun Gangopadhyay and Mr. Kamal Dasgupta, CGCRI, Kolkata]

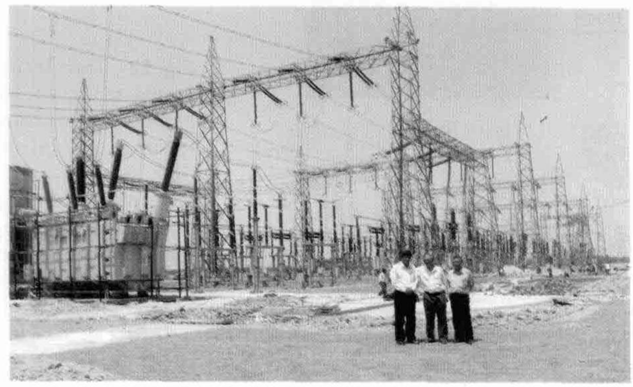

Fig. 16 The substation of Powergrid Corporation of India (near Kolkata, India) where the FBG temperature sensors have been in stalled.

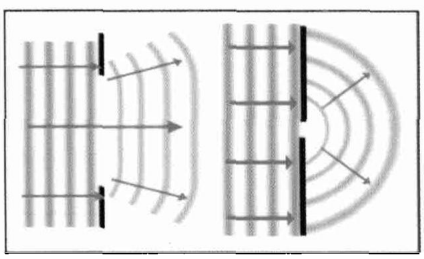

Fig. 17 If an obstacle with a small gap is placed in the tank, the ripples emerge in an almost semicircular pattern; the small gap acting almost like a point source. If the gap is large however, the diffraction is much more limited. *Small*, in this context, means that the size of the obstacle is comparable to the wavelength of the ripples.

[Figure adapted from http://en.wikipedia.org/wiki/Ripple_tank]

Fig. 18 A 50W FASOR; FASOR is an acronym for Frequency Addition Source of Optical Radiation. It is a device similar to a laser where the emitted light is produced in a sum-frequency generation process from two laser sources that operate at a different wavelength. It consists of single frequency injection locked Nd:YAG lasers close to 1064 and 1319 nm that are both resonant in a cavity containing a Lithium Triborate (LBO) crystal which sums the frequencies yielding 589.158 nm light;this radiation is used to excite sodium atoms in the mesospheric upper atmosphere.

[Figure adapted from http://en.wikipedia.org/wiki/Laser]

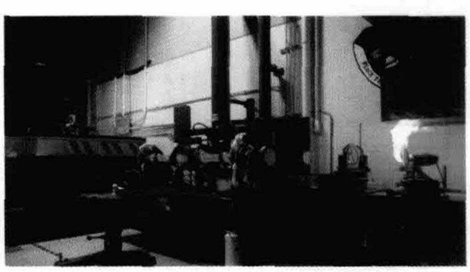

Fig. 19 A test target is vaporized and bursts into flame upon irradiation by a high power continuous wave carbon dioxide laser emitting tens of kilowatts of infrared light.

[Ref.: http://en.wikipedia.org/wiki/CO2_laser]

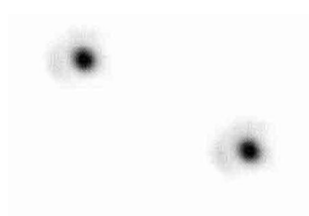

Fig. 20 Image of the binary star Zeta Bootis by a 2.56 m telescope aperture; the Airy disc around each of the stars can be seen.

[Image by Bob Tubbs in http://en.wikipedia.org/wiki/Diffraction]

Fig. 21 1. A diffraction pattern formed by a real double slit. The width of each slit is fairly big compared to the wavelength of the light. This is a real photo. 2. This idealized pattern is not likely to occur in real life. To get it, you would need each slit to be so narrow that its width was comparable to the wavelength of the light, but that's not usually possible. This is not a real photo. 3. A real photo of a single-slit diffraction pattern caused by a slit whose width is the same as the widths of the slits used to make the top pattern.

[Figure adapted from http://www.lightandmatter.com/html_books/5op/ch05/ch05.html]

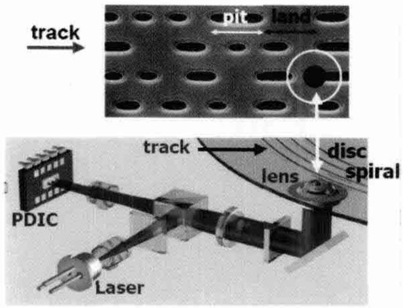

Fig. 22 The Pits and Lands are essentially physical features (protrusion) on the disc surface, which are put there through injection molding. The heights of the pits from the surface are not arbitrary rather it is fixed being equal to $\lambda/4$ where λ is the wavelength of the laser used.

[Figure kindly provided by by Dr Rajeev Jindal and Mr. Giriraj Nyati of Moser Baer India in Greater Noida, India.]

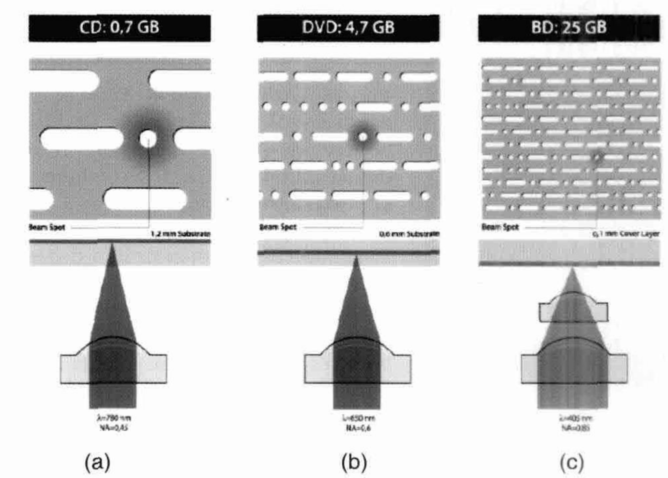

Fig. 24 (a) Infra-red diode laser (λ =780 nm) with a simple objective lens with NA = 0.45. (b) Red laser (λ =650 nm) with increase aperture objective with NA = 0.60. (c) Blue laser (λ =405 nm) with further increase in NA = 0.85.

[Figure kindly provided by Dr Rajeev Jundal and Mr. Giriraj Nyati of Moser Baer India in Greater Noida, India.]

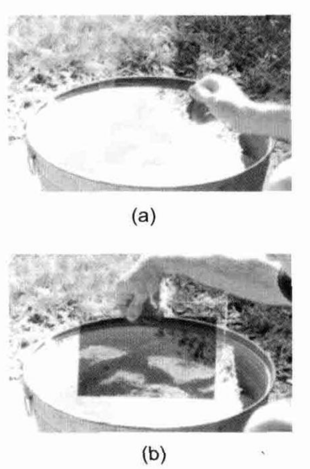

Fig. 26 If the sunlight is incident on the water surface at an angle close to the Brewster angle, then the reflected light will be almost polarized. (a) If the polaroid allows the (almost polarized) reflected beam to pass through, we see the glare from the water surface. (b) The glare can be blocked by using a vertical polarizer and one can see the inside of the water.

[Figure adapted from http://polarization .com/water/water. html]

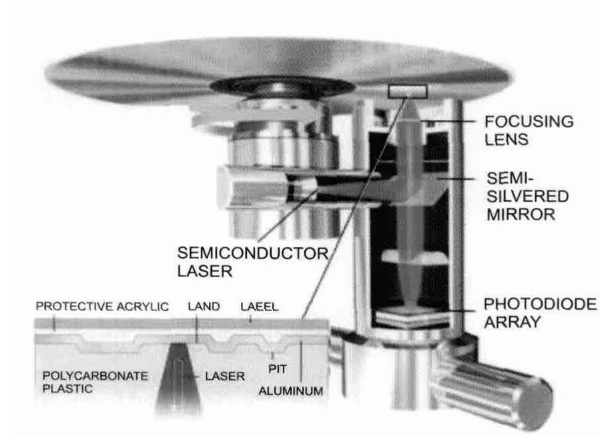

Fig. 23 A CD-ROM substrate is made of optically clear polycarbonate over which the data marks are made through injection molding. The inner hole has a diameter of 15 mm while the overall diameter of the disc is 120 mm and thickness is 1.2 mm. The top of the disc is covered with very thin layer of Silver or Gold to form a reflective layer which reflects back the laser beam so as to be read back. The reflected light is incident on a quadrant photo detector, which converts the light to suitable electrical pulses, which are subsequently processed to extract relevant data. The data capacity of the disc is typically 650-700 MB of Digital Data.

[Figure kindly provided by by Dr Rajeev Jindal and Mr. Giriraj Nyati of Moser Baer India in Greater Noida, India.]

Fig. 25 If the sunlight is incident on the sea around the Brewster angle, then the reflected light will be almost polarized. If we now view through a rotating Polaroid, the sea will appear more transparent when the Polaroid blocks the glare from the reflected light.

[Figure adapted from http://polarization. com/water/water.html]

Fig. 27 A calcite crystal laid upon a paper with some letters showing the double refraction.

[Figure adapted from http://en.wikipedia.org/wiki/Photon_polarization]

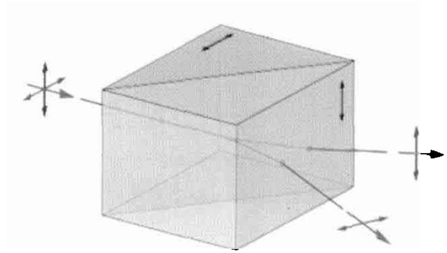

Fig. 28 A Wollaston prism separates randomly polarized or unpolarized light into two orthogonal, linearly polarized outgoing beams. It consists of two orthogonal calcite prisms, cemented together on their base (typically with Canada balsam) to form two right triangle prisms with perpendicular optic axes. Outgoing light beams diverge from the prism, giving two polarized rays, with the angle of divergence determined by the prisms' wedge angle and the wavelength of the light. Commercial prisms are available with divergence angles from 15° to about 45°.

[*Figure adapted from http://en.wikipedia.org/wiki/Wollaston_prism*]

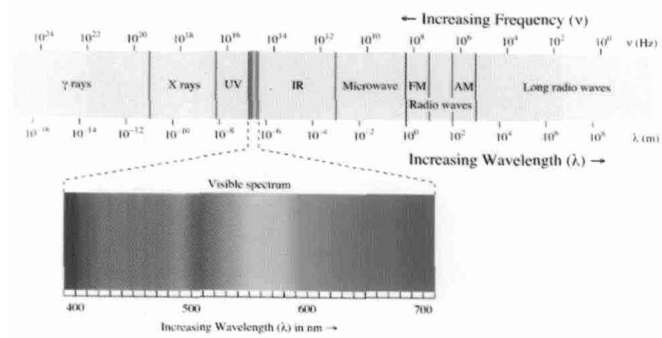

Fig. 29 The electromagnetic spectrum; the visible light occupies a very small portion of the spectrum.

[*Figure adapted from http://en.wikipedia.org/wiki/Electromagnetic_waves*]

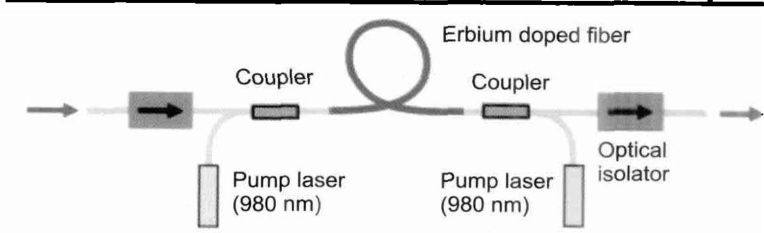

Fig. 30 Schematic setup of a simple erbium-doped fiber amplifier with two laser diodes (LDs) providing the pump power for the erbium-doped fiber.

[*Figure adapted from http://www.rp-photonics.com/erbium_doped_fiber_amplifiers.html.*]

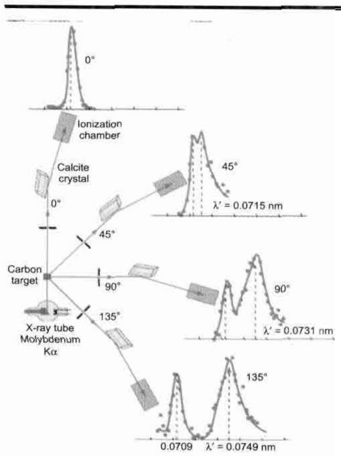

Fig. 31 Compton's original experiment made use of molybdenum K-alpha X-rays, which have a wavelength of 0.0709 nm. These were scattered from a block of carbon and observed at different angles with a Bragg spectrometer. The experimental data is from the original paper of Compton (see Fig. 25.8) – the figure has been adapted from a diagram created by Professor Rod Nave at Georgia State University.

[*Ref. http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html*]

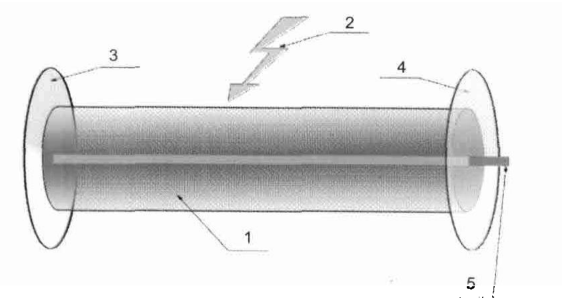

Fig. 32 Principal components of a laser: 1. Active laser medium 2. Laser pumping energy 3. High reflector 4. Output coupler 5. Laser beam.

[*Figure adapted from http://en.wikipedia.org/wiki/Laser*]

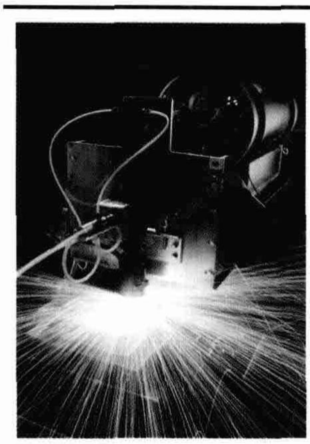

Fig. 33 A 2 kW fiber laser mounted to a robotic system cutting mild steel. Figure downloaded from the Internet.

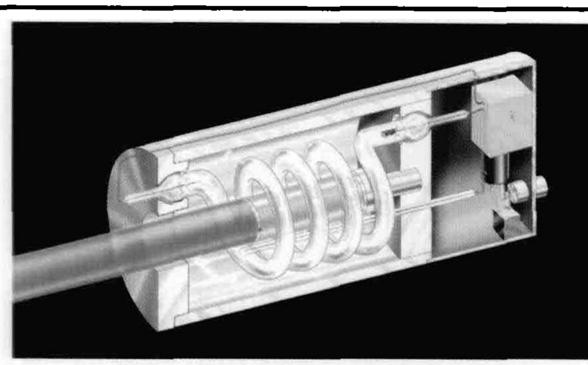

Fig. 34 The first ruby laser.

[*Figure adapted from http://en.wikipedia.org/wiki/Ruby_laser*]

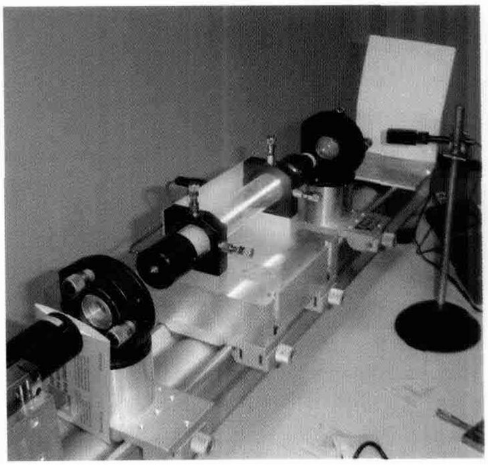

Fig. 35 A helium-neon laser demonstration at the Kastler-Brossel Laboratory at Univ. of Paris. The glowing ray in the middle is an electric discharge producing light in much the same way as a neon light. It is the gain medium through which the laser passes, *not* the laser beam itself, which is visible there. The laser beam crosses the air and marks a red point on the screen to the right.

[*Figure adapted from http://en.wikipedia.org/wiki/Laser*]

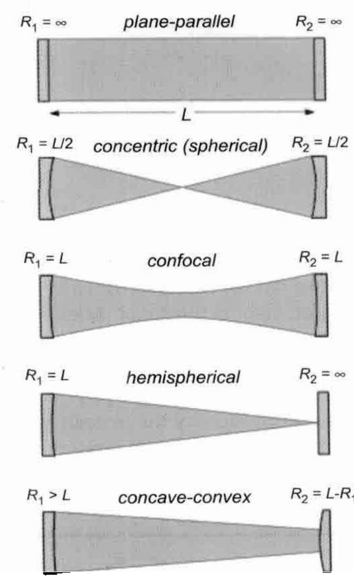

Fig. 36 Different configurations of the optical resonator.

[*Figure adapted from http://en.wikipedia.org/wiki/Image:Optical-cavity1.png*]

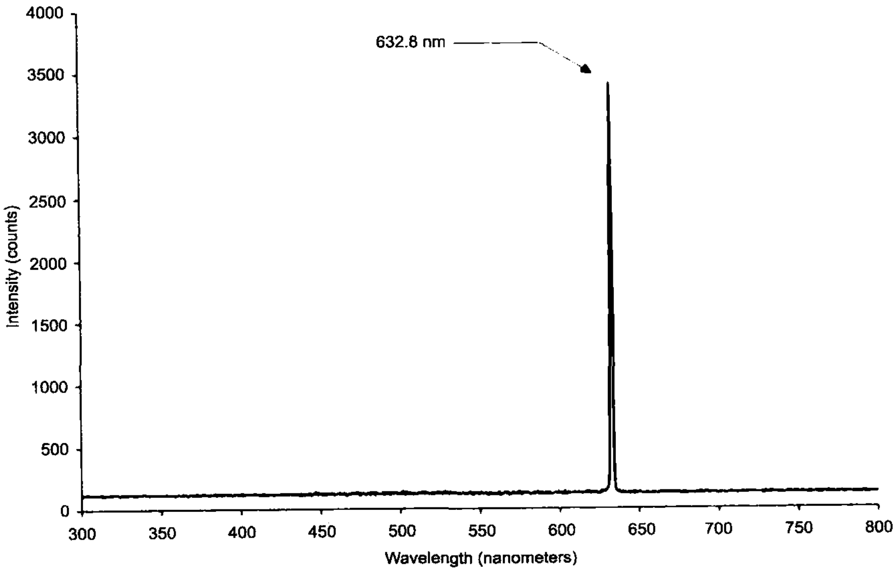

Fig. 37 Spectrum of a helium neon laser showing the very high spectral purity intrinsic to most lasers.

[*Figure adapted from http://en.wikipedia.org/wiki/Helium-neon_laser*]

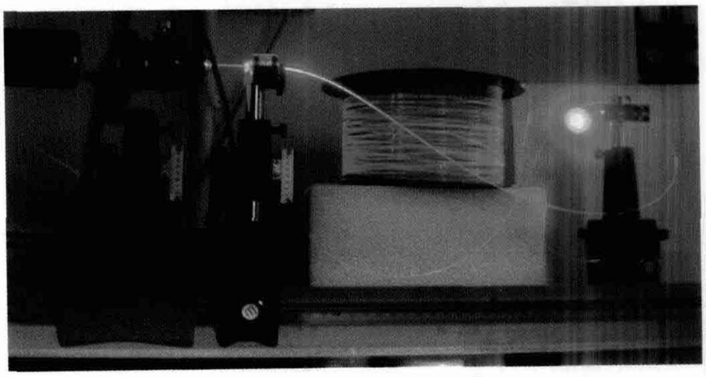

Fig. 38 A step index multimode fiber illuminated by HeNe laser with bright output light spot. The light coming out of the optical fiber is primarily due to Rayleigh scattering. The fiber was produced at the fiber drawing facility at CGCRI, Kolkata.

[*Photograph courtesy: Dr Shyamal Bhadra and Ms Atasi Pal of CGCRI, kolkatta*]

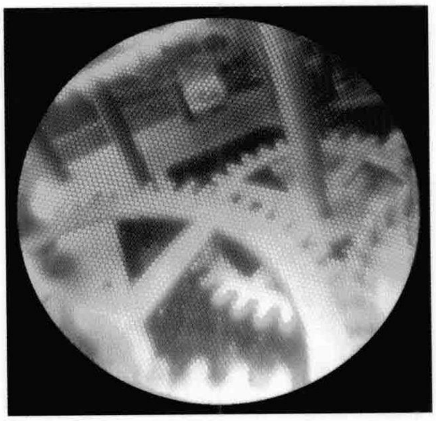

Fig. 39 A low quality fiberscope (with approximately 6000 fibers) observing the inside of an antique clock mechanism. Note how individual fibers are discernable, as it only relays one general color.

[*Figure adapted from http://en.wikipedia.org/wiki/Fiberscope*]

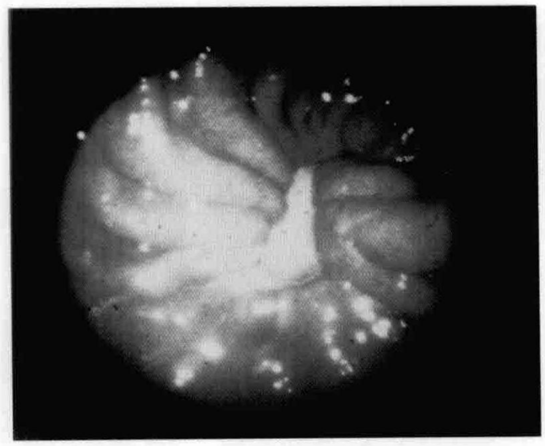

Fig. 40 A stomach ulcer as seen through a fiber endoscope as shown in Fig. 27.11 (a).

[*Photograph courtesy: United States Information Service, New Delhi*]

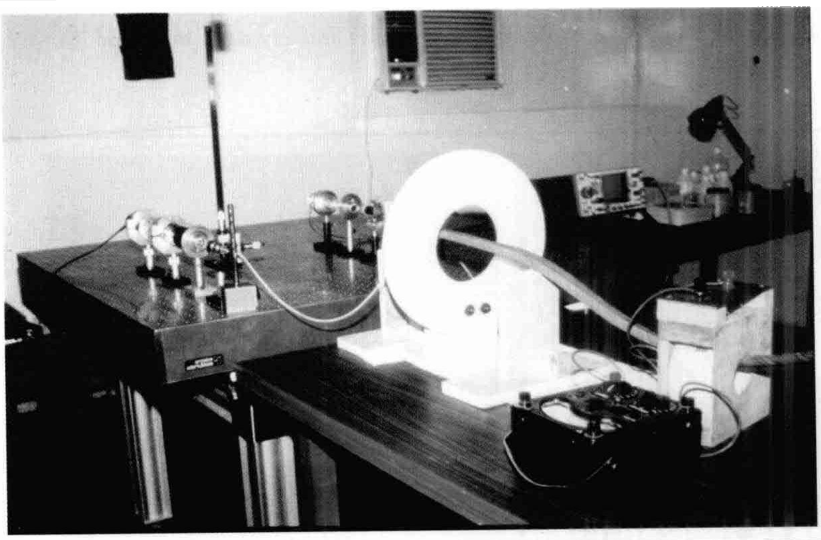

Fig. 41 An experimental setup to measure Faraday rotation in optical fibers because of large current passing through a conductor.

[*Photograph courtesy: Professor Chandra Sekhar and Professor K Thyagarajan, IIT Delhi*]

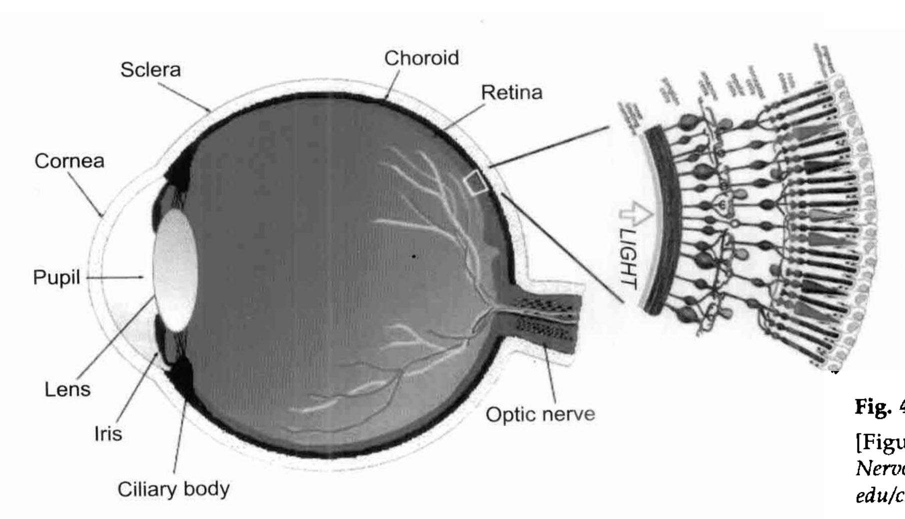

Fig. 42 The rods and cones of the eye.

[Figure *adapted from http://www.biologymad.com/NervousSystem/eyenotes.htm and http://faculty.washington.edu/chudler/retina.html.*]