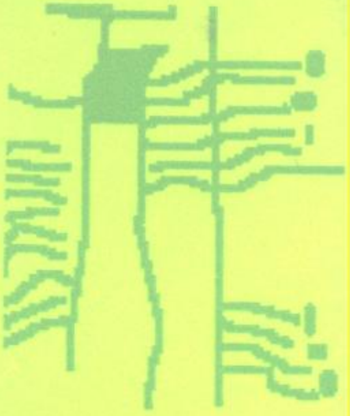
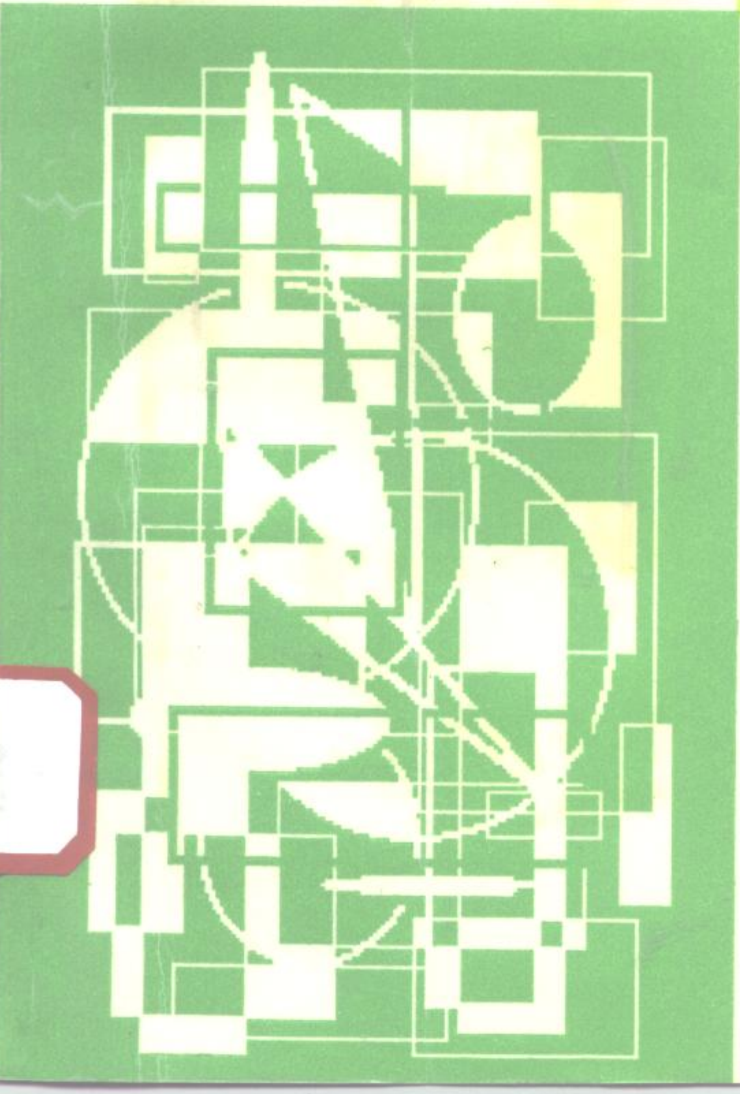
英文版

导波光学实验

Guided Wave Optics Experiments



Shen Qishun　　（沈启舜）
Gong Xiaocheng（龚小成）编



GUIDED WAVE OPTICS EXPERIMENTS

上海交通大学出版社

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Shen Qishun （沈启舜）
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Summary of Contents

Unlike many other texts written on the subject of Guided Wave Optics, this book devoted to technical content, i. e. measurement and fabrication technology. The book consists of six parts; Excitation of Guided Wave [Experiment 1～3]; Waveguide Parameter Measurement [Experiment 4～6]; Practical Three Dimensional Waveguides [Experiment 7～9]; Electrooptic Effects of Guided Wave [Experiment 10～17]; Acoustooptic Effects of Guided Wave [Experiment 18～19] and Optical Waveguide Design, Fabrication Techniques [Experiment 20～21].

This book format enables the reader to use this volume as a coordinated treatise on the guided wave optical area or to refer to individual experiment for more specialized purpose. As a result, the text may be used as the textbook for undergraduate and graduate students in electric and electronic engineering, radio technology and communication engineering, applied physics.

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Preface

Guided Wave Optics is one of the fundamentals of the high technology field related to Optical Fiber Communication,Optical Signal Processing and Optical Computing etc. Because light wave as the carrier of signal reveals a lot of advantages such as high speed, large capacity and the capability of parallel processing, photonic devices which exploit the light wave as signal carrier is rapidly emerging in ever expanding area of science and technology where electronic devices have dominated. Accordingly,Guided Wave Optics,as one of the fundamentals of photonic devices, is demonstrating great vitality.

Most of the published text books on Guided Wave Optics are limited to the interpretation of the physics concepts and basic theories. As a matter of fact, Guided Wave Optics contains rich technical content. However, to the best of my knowledge, there have not been a single textbook devoted to the systematic discussion of experiments of Guided Wave Optics. In order to fill the gap, Associate Professor Shen Qishen and Professor Gong Xiaocheng, the faculty members of the Department of Applied Physics,Shanghai Jiao Tong University,with their experiences in teaching and research work on Guided Wave Optics,have written this book named *Guided Wave Optics Experiments.*

The book consists of six units,Excitation of Guided Waves, Measurement of Waveguide Parameters, Three Dimensional Waveguides, Electrooptic and Acoustooptic Effects of Guided

Waves and Fabrication of Waveguides; 21 experiments in text and an Appendix. Purposes, background knowledge, apparatus, procedures and problems are given for each experiment. This book may be used as the textbook for undergraduate and graduate students in electric and electronic engineering, radio technology and communication engineering, applied physics, optoelectronics and solid state electronics. It can also serve as the references for researchers in related science and technology branches. I believe this book which is written in English will be very useful in training the students not only to raise their experimental skills but also to improve their English.

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CONTENTS

Unit I Guided Wave Excitation

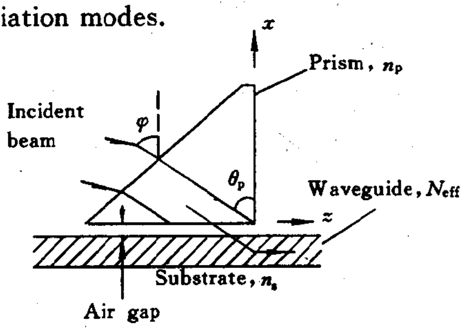
Experiment 1. Guided Wave Excitation Using Prism Coupling Method

Purposes:

1. To understand the principle of the prism coupling method.
2. To learn the experimental method of coupling.
3. To observe the m-line.

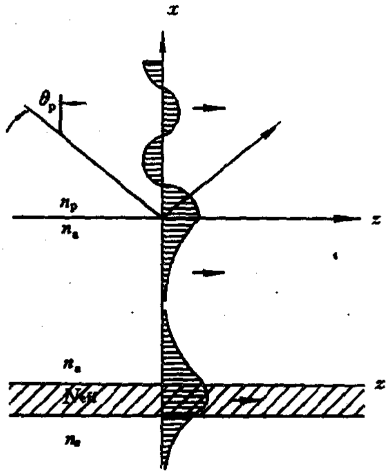
Background:

Prism coupling method is a convenient method for light beam into and out of the optical waveguide. Prism couplers are also modes converters capable of transferring energy between guide modes and radiation modes.



(a)

Fig. 1.1 Prism coupler
(a) *Excitation guided wave*



(b)

(b) *Enlarged view of the prism-air-gap-waveguide interface and optical field distribution*

1. Coupling Mechanisms

Fig. 1. 1 illustrates the physical mechanisms of the prism coupling. When a light beam is incident onto the base of the prism at an angle θ_p larger than the total internal reflection angle, the light will be total internal reflected, yielding an evanescent wave below the prism-air interface. The evanescent wave has a propagation constant $n_p k \sin \theta_p$ along the Z direction, here k is the wave number in the free space, n_p is the refractive index of the prism. In the meantime, the waveguide guided mode also carries an evanescent wave above the air-waveguide interface with a propagation contant β along the Z direction as shown in *Fig. 1. 1* (b). Now if the air gap between the prism base and the waveguide surface is reduced in order that the two evanescent waves may reach the other interface with appreciable optical field mag-

nitude. The evanscent wave at the other interface will leak into the other side of system,causing the prism and waveguide to be coupled.

2. Input coupling

For the case of input coupling, the light beam arrives from the inside of the prism toward the air gap. The evanescent wave extend from the prism base to the air-waveguide interface and induces an optical field in the waveguide having a propagation constant equal to $n_p k \sin \theta_p$. This propagation constant may not correspond to an allowed propagation constant β of the particular guided mode in the waveguide. However, this propagation constant can be easily adjusted by varing the incident angle ϕ of the light beam. As long as the prism refractive index n_p is larger than the refractive index of the waveguide, there is always an angle to cause that propagation constant of the induced optical field is equal to the propagation constant β of the guided mode, i. e.,

$$\beta = N_{eff}\, k = n_p k \sin \theta_p \tag{1.1}$$

where, N_{eff} is the effective index of the guided mode.

Eq. 1. 1 is also called phase-matching condition. When the phase-matching condition is satisfied,the induced optical field becomes a guided mode of the waveguide and the incident light power is then transferred to guided mode power.

3. Output Coupling

When the prism coupling is used as an output coupling for an optical waveguide,the guided mode will enter the waveguide area under the prism coupler with evanescent wave reaching the prism-air interface. This in turn induces a field inside the prism with a propagation constant in the Z direction equal to the propagation constant β of the guided mode in the waveguide. If the refractive index n_p of the prism is higher than the effective index of the guided mode, then this induced optical field inside the prism will propagate away from the prism-air interface at an angle θ to the X direction

$$\theta=\sin^{-1}(\beta/n_p k) \tag{1.2}$$

Thus the guided mode is coupled out by this prism as shown in *Fig. 1. 2.*

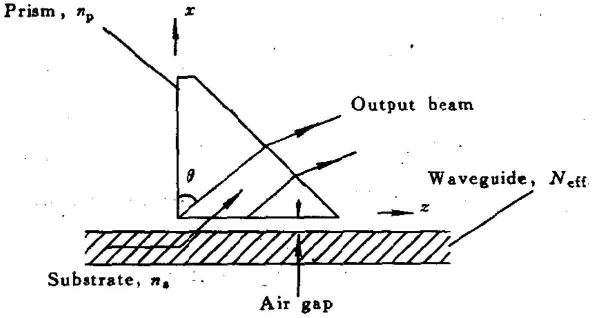


Fig. 1. 2 Prism coupler used for output coupling

Apparatus:

He-Ne laser and its holder, He-Ne laser power supply, Polarizer, Objective, Prism coupling stage, xyz-θ micromanipulator stage, Micrometer head, Screen, Rectangular rutile prisms 2

Procedures:

Fig. 1. 3 shows the practical experimental technique for prism coupling.

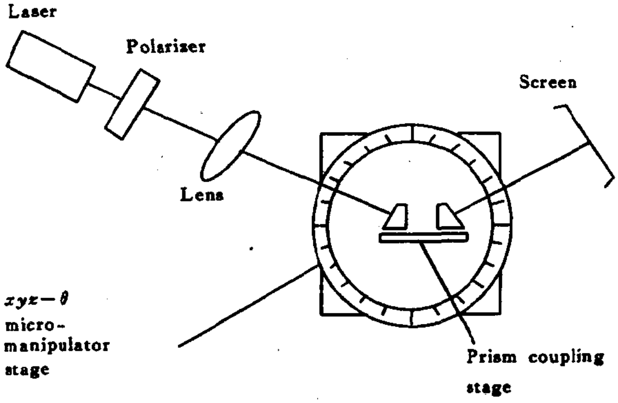


Fig. 1. 3 Schematic arrangement of prism coupler measurement

1. Preparation

Two high quality optical rutile prisms (which refractive indices are greater than the waveguide index) with precisely polished base planes and edges are required. A xyz-θ micromanipulator stage is used to mount the waveguide and prisms and adjust the incident angle of the light beam and its position. The prism is pressed to the waveguide surface using a micrometer head adjustment mechanisms so that the thickness of the air gap can be changed through some rather small elastic deformation of the fixed waveguide by applying slight pressure on the backside of the prism as shown in *Fig. 1. 4*. In order to obtain high coupling efficiency between the prism and waveguide, the air gap should be smaller than 1μm, which is to be recognized by the appearance of causing interference frings on the prism bottom. In this case, the prism and waveguide must be cleaned sufficiently to avoid introducing of dust.

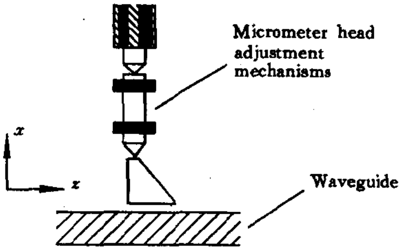


Fig. 1. 4 Mechanisms for prism holding and adjustment

2. The guided mode excited

The laser beam through a lens is focused at the position near the corner edge of the prism base. In order to excite guided mode, the incident angle and the position of the incident light beam must be adjusted carefully. Ordinarily, guided mode excitation is associated with the streak resulting from guided wave scattering. We can find whether the guided mode is excited or not through observing the streak on the waveguide surface. Attention will be paid that the intensity of streak is very sensitive to the incident angle.

3. *M*-line observation

When θ_p is adjusted so that $n_p k \sin\theta_p$ is equal to the propagation constant β_m of guided mode order m, i. e. ,

$$\beta_m = n_p k \sin\theta_p \qquad (1.3)$$

The guided mode order *m* in the waveguide is excited and can be taken out by using an output prism. The output light beam projected on a screen is appeared as the pattern *m*-line since it corresponds to the excited mode order *m*. With the rotation of the input prism, a series of different *m* order guided modes will be excited and different *m*-line is appeared on the different position of the screen.

Problems:

1. A strontium prism ($n_p = 2.32$) is used as an output coupler to couple light out of a Ta_2O_5 waveguide ($N_{eff} = 2.09$). Three *m*-lines are visible at angles θ_p of 36.5°, 30.2° and 24.6° from the waveguide surface. The output face of the prism makes an angle of 60° with the waveguide surface and wavelength λ_0 is 9050 Å. What are the propagation constant of the three modes?

2. If a rutile prism ($n_p = 2.50$) is used as an input coupler to the same waveguide as in problem 1. What angle should the incident light beam make with the waveguide surface to efficiently couple into the lowest order mode? Assume the input face of the prism makes an angle of 60° with the waveguide surface.

Experiment 2. Guided Wave Excitation Using Grating Coupling Method

Purposes:

1. To understand the principle of grating coupling .
2. To observe the phenomena of grating coupling for exciting guided mode.

Background:

Grating coupler is one kind of fine structures fabricated in waveguide structure with periods comparable to their optical wavelength. Like prism couplers, grating couplers are also capable of transferring energy between guided modes and radiation modes if a certain condition is satisfied for its periods. The fundamentals of grating coupling is explained with reference to *Fig. 2. 1.*

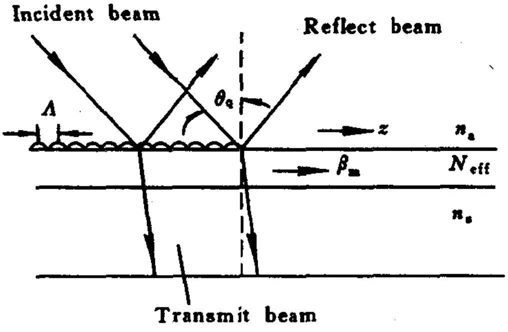


Fig. 2. 1 Schematic diagram of grating coupler

Because of its periodic characteristics, the grating pertubes the guided mode in the region beneath the grating and causes each of guided modes to have a set of spatial harmonics with Z direction propagation constants given by[1]

$$\beta_q=\beta_m+\frac{2\pi q}{\Lambda} \quad (q=0,\pm 1,\pm 2\cdots) \tag{2.1}$$

where, β_m close to the propagation constant of a guided mode m order in the waveguide without grating, Λ is the periodicity of the grating.

If

$$\beta_q=\frac{2\pi}{\lambda_0}n_a \sin\theta_q$$

i.e.,

$$\beta_m=\frac{2\pi}{\lambda_0}n_a \sin\theta_q-\frac{2\pi q}{\Lambda} \tag{2.2}$$

where n_a and λ_0 are the refractive index and wavelength in the air, respectively, θ_q is the incident angle of an unguided incident optical beam.

Eq. 2.2 is also called phase matching condition. Because of the negative values of q, the phase matching condition *Eq*. 2.2 can now be satisfied even though

$$\beta_m>\frac{2\pi}{\lambda_0}n_a$$

Since all of the spatial harmonics of each mode are coupled to form the complete surface wave field in the grating region, energy introduced from the beam into any one of the spatial harmonics is eventually coupled into waveguide and becomes guided mode when it travels and passes the grating region. Thus, the grating coupler can be used to selectively transfer energy from an optical beam to a particular guided mode by properly choosing the angle of incidence.

The energy of guided mode can also be coupled out by a proper angle of output beam from the correspounding, particular guided mode. Though grating couplers are able to be used as an output coupler, its coupling efficiency is rather small because a lot part of incident energy generally transmit the waveguide and lose in the substrate or couple to high order diffraction beam produced by grating. Thus, in this experiment, we use a prism coupler as the output coupler instead of the grating output coupler to get good practical results.

Apparatus:

He-Ne laser and its power supply, Polarizer, Objective, Prism coupling stage, Precision rotational stage, Photodetector, Dual axis precision translation stage

Procedures:

The experimental arrangement is shown schematically in *Fig. 2. 2*

1. The sample is mounted on the translation stage similar to Experiment 1 only the grating coupler is used as input coupler.

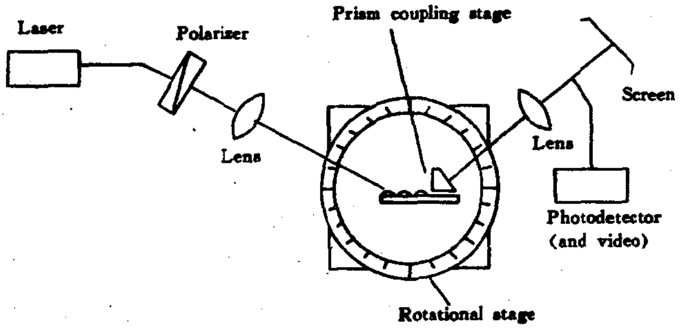


Fig. 2. 2 Experimental configuration for grating coupler