Chapter 1

Introduction

In multimedia era, the optical data storage plays a key role because the optical data storage has several advantages. For example, it is inexpensive easy to manufacture and carry. Because people aspire to enjoy the large size display, the capacity is growing from compact disk (CD) and Digital Versatile Disc (DVD) to High Density Digital Versatile Disc (HD-DVD) and other future video-audio broadcast. Moreover, in order to let the movie play smoothly, the data rate also increases rapidly.

Based on different applications, there are several types of optical data storage, including read-only memory (ROM), write-once-read-many (WORM) and rewritable (RW). A common example of ROM is the CD and DVD. CD was introduced in 1983 and DVD was unified the specifications in 1995. Now the next generation optical data storage, HD-DVD has been proposed. Data are stored as patterns of embossed pits that produce changes in reflectivity as the readout beam scans over them. The optical components in the CD player are comparatively simple, since the only function of the device is to readout the data through the plastic substrate. WORM media are useful for customers that wish to record personal information permanently. Compared with CD players, more issues should be considered since more light energy has to be focused on the recording layer during the writing process. The most popular WORM media is CD-R (CD-Recordable) and DVD±R (DVD±Recordable). Organic dye material is locally burn by the focused laser beam, thereby leaving a location where a change in reflectivity can be detected. Rewritable media differ from WORM in that data pattern can be erased, thus the storage layer can be re-used for the new data. The main usage of the rewritable media is to store the information that needs not to be updated frequently, such as digital camera images, motion pictures, and TV-Programs. Consequently, the rewritable media are useful for applications in the video and entertainment, but inconvenient for use in frequently renewed data, such as the computer data files. In general, the rewritable recorder is more complicated than the WORM recorder because of additional complications in either erasing or readout.

Rewritable optical disks have two major recording media: magneto-optical (MO) and phase change (PC) optical disks. The most popular MO recording material system is TbFeCo, whose perpendicularly magnetized domains can be altered with the application of an external magnetic field and heat energy simultaneously. At room temperature, the orientation of the magnetic domain is very resistant to change. As the medium is heated with a focused laser beam to the Curie point (about 200°C) In MO recording, an external field H is applied to determine the magnetization direction of the domain. The recorded marks can be detected by the polarization rotation due to the Kerr effect. In PC media, the reflectivity of alloy GeTe-Sb_2Te_3-Sb pseudo-ternary material changes between the crystalline and amorphous phase. Before recording data on PC disks, the disordered structure of the as-deposited amorphous state has to be initialized to the ordered structure of the crystalline state as the background, unrecorded state. In writing, the phase change media are melted and quenched to the amorphous state; in erasing, the phase change media are annealed to crystalline state. The reflectivity difference between the amorphous and crystalline states of the phase change materials is the key way to recognize the digital signal.

Practically, each type of media requires different optical means to read, write, and erase information in the recording layer. The rewritable drive is the most complicated one among these three main types mentioned above. Therefore, the main considerations of the optical path and pickup design in the rewritable device are introduced in the following section.

1.1 Optical path in rewritable system

The optical path is designed to maximize the signal-to-noise ratio of the data detection and to provide robust tracking and focusing servo signals. These goals must be traded off with optical efficiency, cost, and complexity. The typical optical paths for the rewritable PC and MO system are shown in Figs. 1-1 and 1-2, respectively.

In PC recording, the polarization beam splitter (PBS) and quarter-wave plate provide an optical circulator that passes all of the linearly polarized light from the laser diode to the disk but redirects all the reflected light to the data and servo detectors.

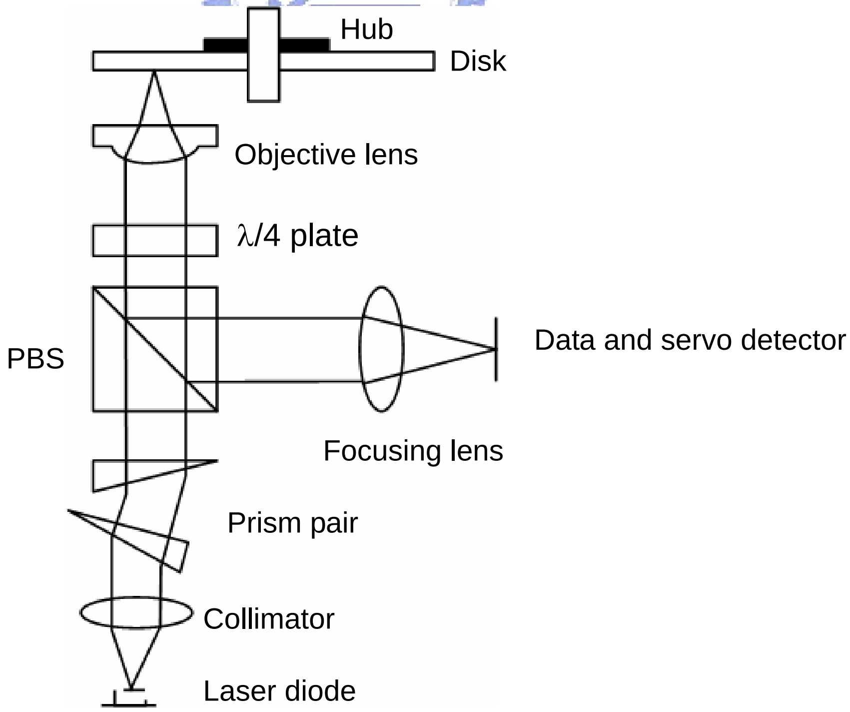

Fig. 1-1 Optical path for a phase-change (PC) storage system.

In MO recording, a leaky polarized beam splitter (LPBS) with adjustable leak ratio is used, instead of PBS used in PC system. About 70 to 80% of linearly polarized light from the laser diode is adjusted to pass through LPBS. The state of polarization in Fig. 1-2(a) is linear. The reflected light is recollimated by the objective lens after interaction with the magneto-optical recording layer. The state of polarization at Fig. 1-2(a) now is rotated slightly, depending on the direction of magnetization in the medium known as the polar Kerr effect. The LPBS redirects all the y polarization and part x polarization to the data detector. The state of polarization at Fig. 1-2(b) is similar to the reflected beam at Fig. 1-2(a); the rotation angle can be enhanced by increasing Y/X ratio. The beam then passes through a half-wave plate that rotates the polarization to a nominal value of 45°, as shown at Fig. 1-2(c). A Wollaston prism and two detectors are then used to provide a differential signal to the signal process. Due to the strong birefringence of the Wollaston prism, the two polarization components of the beam are spatially separated, thus having different focal positions.

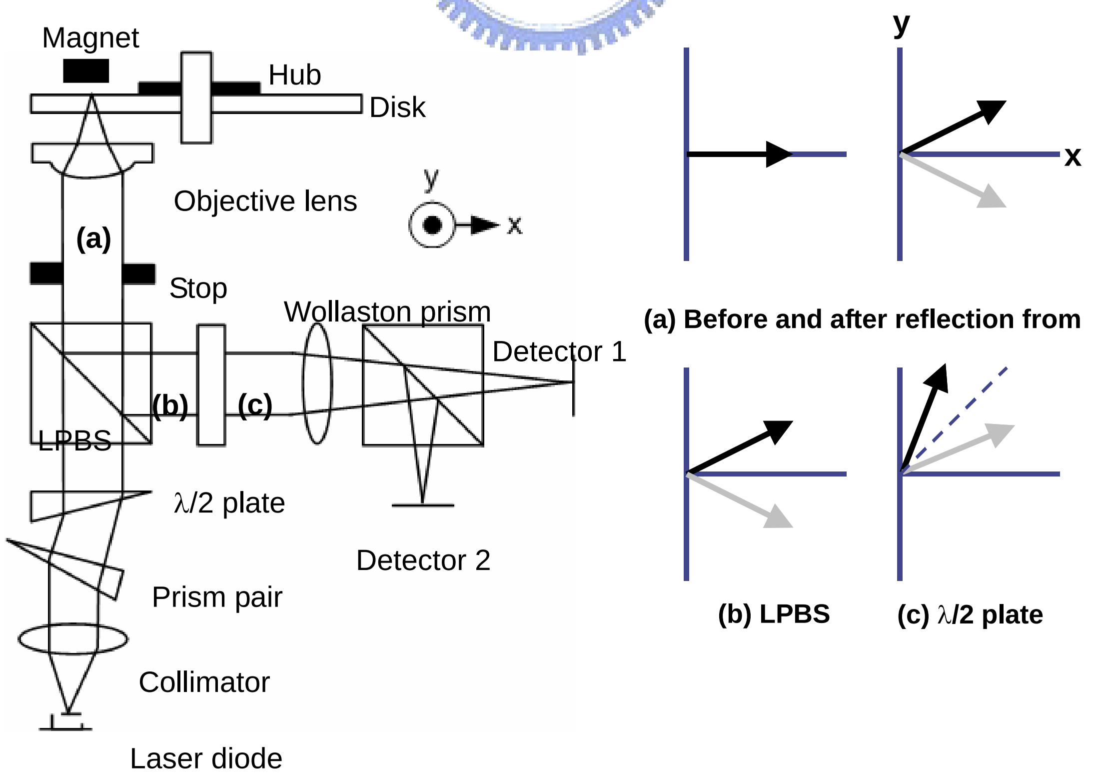

Fig. 1-2 Optical paths for a magneto-optical (MO) storage system

1.2 The development of pick-up head

A conventional far-field optical pick-up head is shown in Fig.1-1, where the laser beam is focused on the recording layer by an objective lens. The optical pick-ups made of discrete components are inevitably large and heavy. Access time of the pickups is determined by the speed of motor and mass of the pickups. However, the speed of motor has the limitation in machinery. Therefore, the mass of the pickup is the dominant factor to determine the access time.

Issues of future pickup improvement include miniaturization and integration. New technology and design are applied to reduce the cost, size, and weight of the opto-mechanical structure for making the device more competitive in terms of price and performance. More details of these new technology and pickup designs are described as follows.

1.2.1 Micro-opto-electric-mechanical-systems (MOEMS) technology

The uses of integrated optics mentioned above have suffered from high coupling loss in and out of waveguides; thus the impact on the overall laser power budget. Until now, as the tremendous improvement in the field of semiconductor electronics, many efforts have been made to transfer the idea of microintegration to other categories, in particular to mechanics and optics to boost the performance. Such efforts are interesting for areas and applications where electronics, mechanics, and optics intergraded and eventually lead to the Micro-Opto-Electric-Mechanical-Systems (MOEMS) techniques.

Recently, a great deal of interest is raised in the monolithic integration of optical pickup by MOEMS technology. The integration not only reduces the assembly cost by eliminating bulk optical elements but also enhances the device's performance.

Examples of new head designs include miniaturization, integration, and multiple beam heads. Each of the above mentioned topics is an active subject of research. Here we only investigate the characteristics of the optical pickup fabricated by MOEMS technology, such as the focused spot size, focusing/tracking servo operation, and the resolution of readout. Three schemes of the integrated optical pickup were introduced: the waveguide with focusing grating [1], the diffractive (or holographic) optical element (DOE; HOE) planar approach [2] and free-space optical bench by surface micromachining techniques [3].

1.2.2 Integrated-optic implementation based on waveguides and holographic (diffractive) components

In the first approach, S. Ura *et al.* employed a focusing grating coupler (FGC) as a pickup in record/read mechanism. A FGC is a kind of diffractive waveguide. It has chirped and curved grating pattern to couple a guided wave from laser diode to focus in the free space, as shown in Fig. 1-3. The error signals are also required for the automatic servo operation. The focusing/tracking error detections are based on the foucault/push-pull methods, respectively, which are modified for implementation by diffractive components in a waveguide.

The 3dB focus spot width was measured approximately 2 μm, while the theoretical diffraction-limited value is 1.4 μm. Major aberrations induced by the possible fabrication errors are astigmatism and coma, which easily cause the deterioration of the focused spot. Since holographic optical elements (HOE) are dispersive elements, the wavelength deviation is also an issue in the optical design and fabrication accuracy.

The fabrication accuracy required to obtain the diffraction-limited focused spot becomes stringent with increasing NA of the focusing grating. For example, the maximum tolerance error in focusing grating coupler (FGC) linear dimension and wavelength deviation at NA of 0.24 are estimated to be approximately ±0.6% and ±0.9%, respectively, while 0.45 NA requires ±0.09% and ±0.1%, respectively.

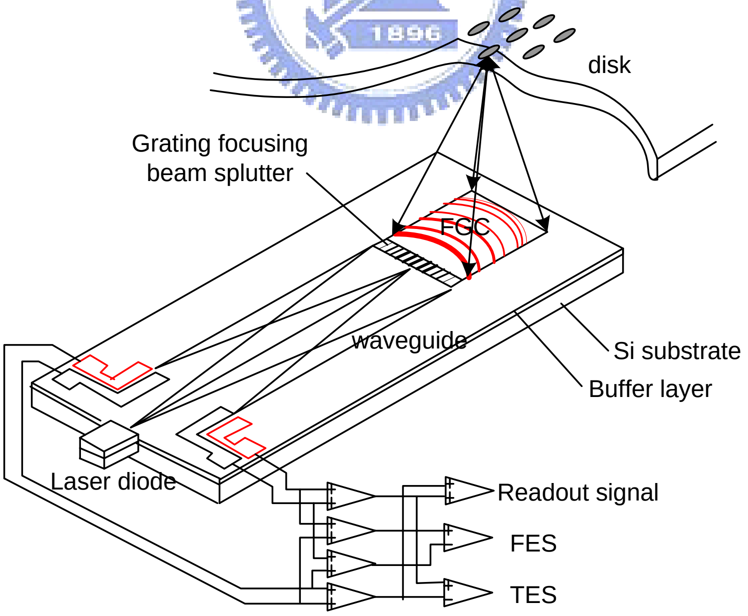

Fig. 1-3 Schematic of the integrated optic disk pickup (IODPU). The curved and chirped grating incorporate the input/output coupling and the focusing by the wavefront conversion based on holographic principle.

1.2.3 Planar pickup based on glass substrate light guide

The use of diffractive optical elements (DOEs) to replace individual refractive optics is a promising development. T. Shiono *et al*. employed planar optics integrated with various diffractive structures on a glass substrate. The glass substrate is used as a light guide in whom the beam follows a zigzag optical path, as shown in Fig. 1-4. By this approach, the beam hits those diffractive elements in order. The focusing/tracking error detections are based on the foucault/push-pull methods, respectively, which are achieved by the off-axis blazed structure called reflection-twin-focusing beam splitter.

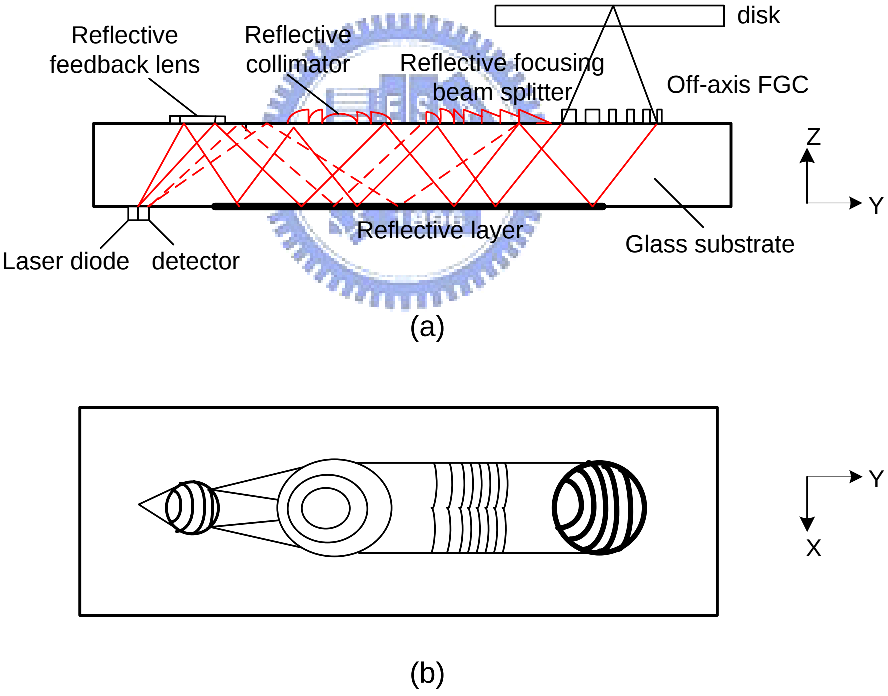

Fig. 1-4 Schematic of the planar optical disk pickup based on glass-substrate based: (a) side and (b) plane view.

The focused spot in FWHM is about 1.0 μm at λ = 0.63 μm. This value is very close to the diffraction-limited (0.98 μm). Theoretical efficiency of the system was about 46 %, with reflection loss neglected at each interface. This approach requires precision alignment on both sides of the substrate and is very sensitive to optical crosstalk of the high-order diffraction beams.

1.2.4 Free space three dimensional micro-optical bench

Silicon surface micromachining proposed by M. C. Wu *et al*., a Si substrate serves as a micro-optical bench on which three dimensional optical elements, micropositioners, and actuators are monolithically fabricated. The all configurations of this technology are the same with the conventional pickup but on an extremely tiny size. The schematic drawing of the pickup is shown in Fig. 1-5. The NA of the focusing micro Fresnel lens was measured to about 0.17. In this structure, fine optical alignment (< 0.1 μm) and dynamic tracking can be achieved by on-chip microactuators with electronic driving.

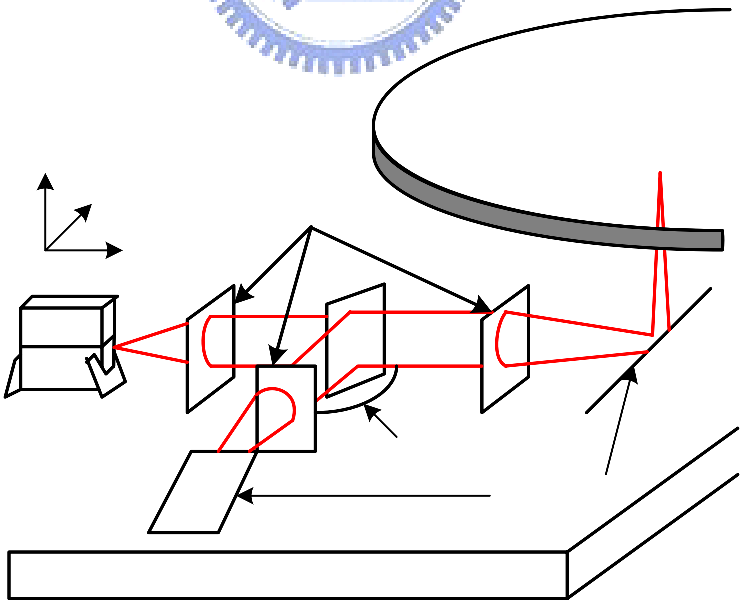

Fig. 1-5 Optical module structure.

1.3 Planar fiber-base optical head

The previous sections show the good ideas in optical pickup head but they still have some limitations. The efficiency of the waveguide is low and the most loss is from laser coupling into waveguide. The trade-off between resolution and alignment limits the efficiency of DOEs. Due to the characteristics of silicon surface micromachining, how to lift up the planar components is the critical issue for success in free space three dimensional micro-optical bench.

The fiber-based optical pickup can be modified by separating the waveguide chip and the laser diode (LD), and linking them by an optical fiber. In the fiber-based pickup, only the waveguide part is actuated for servo operation. The large reduction in weight of the moving part allows higher speed operation. Another advantage of the fiber-based pickup is that an optical isolator can be easily inserted between the LD and the fiber to stabilize the lasing.

The limitation of fiber-base pickup head is that NA is too small and spot size is too large. The solid immersion lens (SIL) is added into the planar fiber-base pickup head for increasing NA. The schematic view of the proposed planar fiber-base optical head is shown in Fig.1-6. This module is planar and can be mounted on a slider and suspension like the magnetic flying head in HDD system. High quality beam is delivered into the system by single mode fiber. Optical fiber with a microlens at its front end used as a light guiding and beam control device was proposed. [4] Meanwhile, the recording density can increase by using near-field recording with the combination of Solid Immersion Lens (SIL) and aperture systems. [5-7] The incident light from the fiber fixed by well defined V-groove was focused by the fiber lens and then bent 90 degree by the mirror on V-groove to be guided to SIL precisely. The beam size is further reduced by the SIL and aperture.

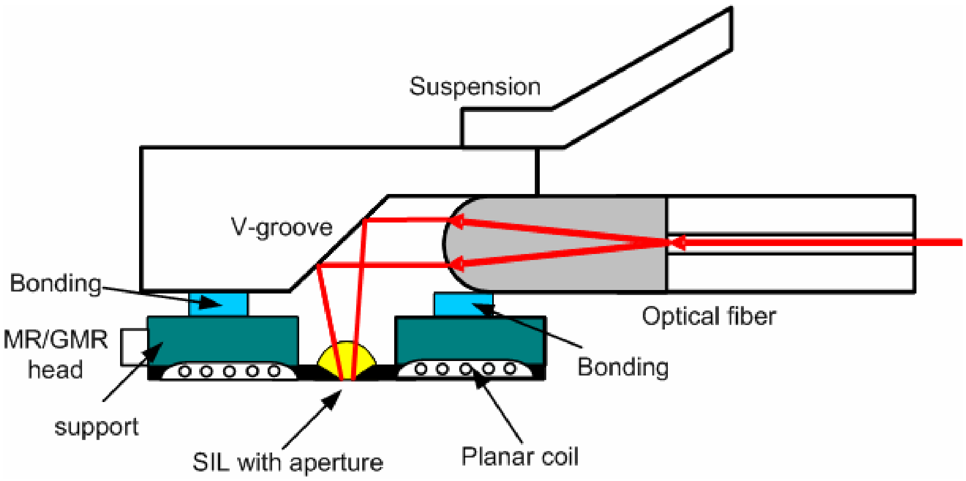

Fig. 1-6 Planar fiber-base optical head

1.4 Research objective

The planar fiber-base pickup head was proposed and each component was fabricated. The module should be designed and optimized to satisfy the limitations in the fabrication and assembly process. The system tolerance was also analyzed because the signal degradation caused from fabrication and assembly process, such as misalignment and dimension variation, should be considered. The goal of thesis is to design the system, analyze the tolerance in fabrication and assembly process, and demonstrate the feasibility of integrating fiber-base pick-up head.

1.5 Organization

The thesis is organized as follows: The fundamental theory of each component is described in **Chapter 2**. In **Chapter 3**, according to fundamental theory of each component, the optimized module is presented. The tolerance in fabrication and assembly process are analyzed. The fabrication process and measurement result are in **Chapter 4**. The measurement result is compared with simulation. Finally, the conclusions of this thesis and future works will be presented in **Chapter 5**.