

Communication Component Fabrication Educational Program for Information Technology*

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Since the propagation of global communications, information technology (IT) plays a very important role in improving quality of life. Educational institutions have the responsibility to educate students with knowledge in this field. A fundamental IT educational program is currently conducted in the College of Engineering, National Chung Hsing University, Taiwan. This IT program is based on three main IT technology subjects: system, design and fabrication. Five subprograms are designed based on the interrelationships between these three subjects. In this paper, we present the teaching goal, curriculum design and teaching outcome of one of these subprograms aiming for enhancing the students' ability in communication component fabrication. We focus particularly on the students' ability in system integration including theory, microfabrication, packaging and testing. Course teaching is accompanied with hands-on experiments performed in the supported laboratories. From the student projects, it was found that this subprogram successfully achieved the educational goal. The students were able to integrate the knowledge in class to create innovative communication systems and microfabrication processes.

Keywords: information technology (IT); communication component fabrication; and micro-fabrication.

INTRODUCTION

THE RAPID GROWTH of information technology (IT) has changed the developed world's life-style and economic development pattern. This can be traced from proliferation of universal Internet service, global telecommunication, and computer technology. IT comprises media, communications, electronic transportation and human resources. It is an important industry in Taiwan. It will become the third largest industry following integrated circuits (IC) and flat panel displays (FPD) in this country. Universities must take educational responsibility for all industries and train students with innovative knowledge.

Microsystem and nano-system technologies are essential in the electrical, mechanical and biological fields. They offer versatile capabilities that combine sensing, processing, computing, and actuating functions on the same chip [1]. These technologies use radio frequency systems (RF) on a chip containing hundreds of micro-switches, resonators and other microsystem devices. These emerging technologies have led to evolutionary changes in the IT field. Clear evidences are cell phones with personal digital assistants (PDAs) providing access to all kinds of information and optical switches enabling high-speed optical

networks for wire-communications. Great investment has been allocated in the past few years into optical microsystems for high-speed optical networks and broadband communications.

Advanced microfabrication methodologies play critical roles in making these technologies viable. For example, Lamb-wave (LW) ultrasonic devices have been shown to be extremely useful for applications in liquid environments [2]. LW devices are usually fabricated on silicon wafers. The fabrication processes indicated the possibility for further size reduction and bandwidth increases in these devices using advanced microfabrication technologies [3]. Parallel optical interconnection devices appear to be suitable for applications featuring low loss cross-talk, small size and low power consumption. Silicon micromachining with high precision has shown to play a decisive role in making these devices effectively by integrating mechanical, electrical and optical functions in a single chip [4]. Because of its importance for future engineers, microfabrication courses have been included in recent university manufacturing education curriculum [5, 6].

Micro-optics provides a great potential in the miniaturization of conventional optical components. It plays an important role in the manufacturing of products such as liquid-crystal displays (LCDs), video cameras, video phones, compact disk data storage, robotic vision, optical scanners and high-definition projection displays [7]. In these products, the micro-lens is an important component

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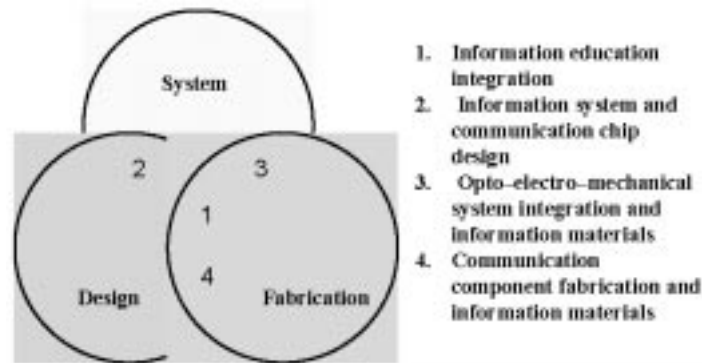


Fig. 1. Interrelationships between IT main subjects.

that determines product performance [8]. The micro-lens is used to enhance the illumination brightness and simplify light-guide module construction. In a laptop display, a 25% increase in light output was reported when micro-lens technology was applied [8]. High accuracy and low fabrication cost are required in micro-lens design to satisfy commercial needs [9]. Currently, several techniques such as UV proximity printing [10] and hot embossing [11] are used in micro-lens fabrication.

In view of the technologies mentioned above, it is clear that IT is an inter-disciplined and developing technology. Students in schools must be trained to possess the fundamental design and fabrication knowledge related to this field. To achieve this goal, an educational IT program is set up and implemented in the College of Engineering, National Chung Hsing University, Taiwan. In the following, the scheme, implementation and result of one of the subprograms are presented. The purpose of this paper is to share the teaching experiences and gain input from the other institutions around the world.

EDUCATIONAL SCHEME

The IT educational program conducted in our university is designed based on three main subjects

in the field of IT: system, design and fabrication. In Fig. 1, the three subjects and their interrelationships are shown. The three subjects are integrated as a unit. System and design are interrelated to information system and communication chip design. Design and fabrication are interrelated to opto-electro-mechanical system and information materials. Design and fabrication are interrelated to communication component fabrication and information materials. Based on these interrelationships, five subprograms are designed under this program as shown in Fig. 2: information system, communication chip design, communication component fabrication, information material and opto-electro-mechanical system integration. These five subprograms are executed by the departments of electrical engineering, mechanical engineering, material engineering and precision engineering. Each subprogram has a steering committee that is responsible for course design, laboratory support, teaching evaluation and future planning. Since hands-on experiments are essential to the IT education, seven laboratories as listed in Fig. 3 are established or re-planned to provide the student with enough facilities to carry out their experiments and designed projects. Junior- and senior-year undergraduate students and graduate students are encouraged to enroll in this program. In this paper, we specifically present the teaching

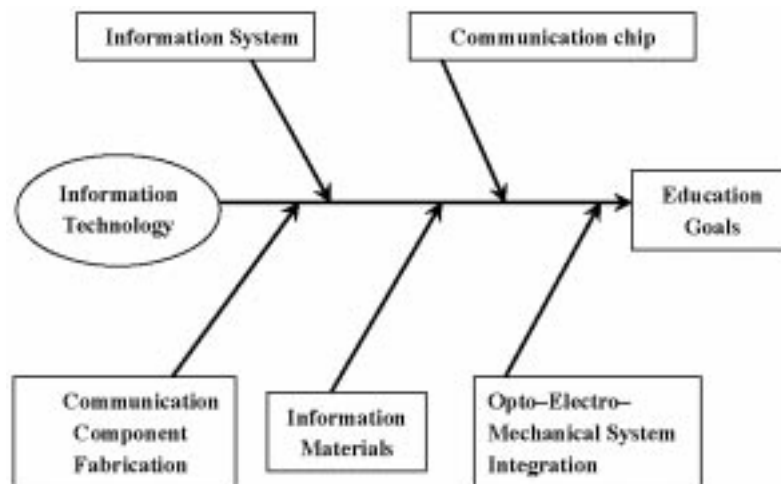


Fig. 2. Schematic of IT educational program integration.

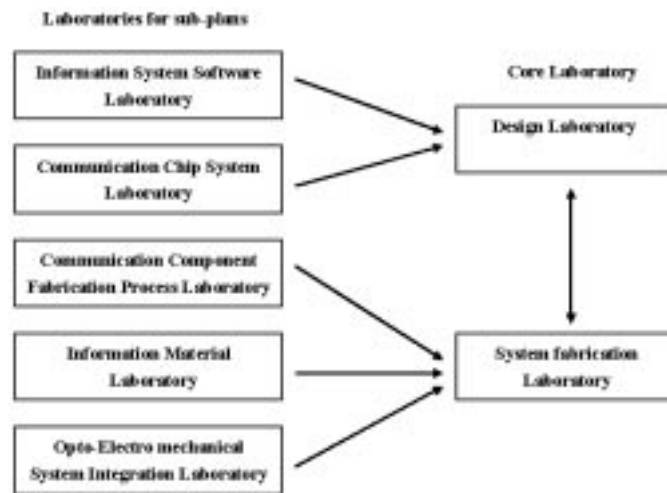


Fig. 3. Laboratories for IT educational program.

activities in the communication component fabrication subprogram.

EDUCATIONAL IMPLEMENTATION

The educational goal of the communication component fabrication subprogram is to cultivate students with component manufacturing process knowledge for wireless and optical communication component fabrications and applications. Training in both theoretical background and experimental skill are emphasized equally in this subprogram. In the following, the course design concept and supported laboratories are described.

Course design

As mentioned above, this program is designed for higher-level students. Students can join this program after they have completed the fundamental courses. For students choosing to enter the communication component fabrication subprogram, eight elective courses, as listed in Table 1, are available for them to take. The basic principle of course design in this subprogram is described as follows. In the first year, two courses are offered: micro-engineering sciences and opto-electro-engineering. This is intended to introduce the theoretical backgrounds regarding microscale physics in mechanics and optics that are essential in the field of IT. In the second year, two courses in microfabrication technology are provided. The objective is to establish the students' knowledge in micromachining techniques. The students' ability in performing micromachining is developed

through support laboratories in these two courses. Basically, two major techniques, silicon- and micromechanical-based techniques, are taught in class and practiced in the laboratories. In the third year, microsystem packaging and micro-metrology courses are offered to provide the student with knowledge in systems integration, packaging, microscale measurement, and testing. The training provided by these two courses is particularly important because students should have the ability to carry out commercial products after graduation. In the final year, special topics in both optical fiber and wireless communications are offered to students. The students must carry out assigned projects using what they have learned in class and other available resources. The student project is individual work conducted under instructor supervision.

Supported laboratories

As mentioned before, hands-on experimentation is the particular focus in this program because it can help the students gain valuable experimental work experience. To enhance the learning outcome, hands-on experiments are performed in parallel with the lectures in most of the courses. Three support laboratories are established or replanned for course teaching. The functions and facilities for these laboratories are described below.

- **Semiconductor micromachining laboratory.** This laboratory originates from the IC industry but with a particular application for micro-electro-mechanical system (MEMS) technologies. It focuses on using semiconductor processing

Table 1. Course design structure.

First year	Second year	Third year	Fourth year
Microengineering Science	Microfabrication Technologies	Microsystem packaging	Special topics on optical fiber communication
Optoelectro Engineering	Micromechanical Machining	Micrometrology	Special topics on Wireless Communication

equipment to develop certain micro-devices. All substrates are based on silicon substrates. The equipments used are the mask aligner, thermal evaporation system, sputtering system, electron-gun system, wafer bonding machine, oxidation oven, dry and wet etching and wafer dicing saw. This laboratory provides students' with training in lithography, wafer bonding and etching, suspended thin films and sacrificial layer processes for microsystems. These technologies can be further extended to devices used in biochemical sensing, heat transfer enhancement and signal sensing.

- **Precision micromachining laboratory.** This laboratory is designed to explore non-semiconductor-based microfabrication processes. The goal of this laboratory is to produce mini/micro systems (typically 1 cm or less in size) with micro-components (typically of 1-100 μm in size) with sufficient tolerance to achieve the desired functionality and repeatability. These micro-devices can be further applied to measurement instruments, commercial electronic products, and other key components. This is a technology-based teaching/research laboratory. Processes such as UV lithography, E-beam writer, micro-electroforming, and micro-molding processes can be performed in this laboratory. Students can use this laboratory to fabricate their own device designs such as functional micro-structure, micro-optics, optical fiber communication components and other micro-elements.
- **Micro-metrology laboratory.** This laboratory plays a supporting role in the development of microfabrication processes. MEMS products usually do not necessarily require very high resolution metrology tools as needed in basic research. Because MEMS structures routinely have relatively large vertical steps in the topography, vertical range of measurement rather than resolution is more important. Two methods that provide reasonable resolution are contact stylus and non-contact optical interference profilometers. Other measurement tools equipped in this laboratory include optical microscope (OM), image measuring system, scanning electron microscope (SEM), atomic force microscope (AFM), α -STEP, and C-V meter. Students are to be trained to operate these equipments fluently and accurately.

The above-mentioned laboratories are planned and managed by the steering committee of this subprogram. In each laboratory, an operation rule is set up for the users to conduct their experiments or projects. The general procedure for applying to conduct experiments in the laboratory is indicated in Fig. 4. Before using these laboratories, the user needs to fill out an application form stating the experiment purpose, equipment planned to use, usage time and safety protection. After receiving laboratory advisor approval, the student may schedule and prepare for the experiment. For



Fig. 4. Experimental laboratory management flowchart.

beginners, basic training and laboratory tour will be given before they can use laboratory equipment.

RESULTS AND DISCUSSION

This educational program is a four-year project sponsored by the Ministry of Education of Taiwan's government starting from 2001 to 2004. This project has entered its second four-year term with continuous support by the government. In running this communication component fabrication subprogram in the first four-year term, we gained valuable teaching experience from all of the participants, including students, faculty and industrial partners. Important tasks carried out in this subprogram during the first four years are listed in Table 2. In the following, the particular subjects taught in the first four-year term are given and discussed. Some of the outcomes from the students' course final projects are presented.

In the first year, courses regarding physical background in microscale dimensions and micro-optics are offered. For students in this field for the first time, these two courses provide students sense and knowledge in MEMS and optical MEMS. In the second year, principle and hands-on projects in making micro-parts in the communication industry are the focus. Both semiconductor and non-semiconductor techniques are taught with appropriate practices. In the third year, microsystem integration in communication components is the focus. System integration is based on previous component manufacturing technologies linked to the related communication systems. The microsystem packaging and testing are particularly emphasized. Communication component packaging is different from that in IC industry packaging and is more complicated in structure. Three basic levels are involved; substrate, part, and system level. The

Table 2. Tasks carried out in communication component fabrication subprogram in the four-year IT educational program

Year	Check points
First	1. Complete fabrication laboratory preparation and users' rules 2. Finish the instruction materials for micromechanical machining subject
Second	1. Complete the instruction materials for microfabrication technologies subject 2. Purchase component metrology and test equipment
Third	1. Establish micro-parts metrology teaching environment 2. Complete component metrology and test equipment
Fourth	1. Offer the subject in optical fiber communication course 2. Offer the subject in wireless communication course

substrate level provides part and signal linkage protection. Several packaging technologies such as hot embossing, ultrasonic bonding, anodic bonding, fusion bonding and electroforming are introduced.

In the fourth year, the special focus is on establishing the students' ability to integrate theory, fabrication, packaging, microscale measurement and testing. Design projects dealing with communication systems are assigned to the students. Component integration into a system is required to be light, small, and convenient. Optical fiber and radio frequency (RF) component integration are particularly emphasized because of their importance in the IT industries. Fiber to the home (FTTH) is required in communication systems and necessary for upgrading the IT industry. Optical fiber components are in increased demand, meaning that optical component companies will need an increased number of students with the related background. RF communications is the other critical branch for IT. Wireless

communications provides convenient, mobile advantages for daily life. Students are required to complete their projects individually.

Some of the student learning activities are described below. Figure 5 shows the tunable VCSEL (vertical cavity surface emitting laser) fabrication. It was developed at a semiconductor micromachining laboratory based on semiconductor processing technologies by students. Facilities for lithography, sputtering, etching, and bonding in our semiconductor laboratories were used to carry out this VCSEL.

In recent years, much attention has been focused on integrating technologies for device miniaturization and emphasizing high device performance. The micro-optical device field is one of the most representative fields for this emphasis because unique optical element fabrication is often required. A micro-ball lens can be used to obtain more efficient light coupling from a laser diode (LD) into a single-mode fiber (SMF). This is necessary for low-loss, high-bit-rate communication systems. The primary challenge for these optical devices results from the extremely stringent submicron alignment tolerance required for high-efficiency coupling. A ball lens can achieve low-cost coupling, but the coupling efficiency of the general ball lens is limited to around 10%. This poor performance is caused by the large spherical size aberration. Increasing the ball lens mode converter performance through a more reliable design has been discussed by many researchers using theoretical or experimental methods. In the microfabrication technology class, students presented new methods based on the heat reflow of two polymer layers to fabricate an integrated micro-ball lens array onto a planar substrate, as shown in Fig. 6 [12]. This device provides a platform for fiber coupling as sketched in Fig. 7. The students also used these micro-ball lenses to measure light coupling, as indicated in Fig. 8. The measured result is shown in Fig. 9. A laser light

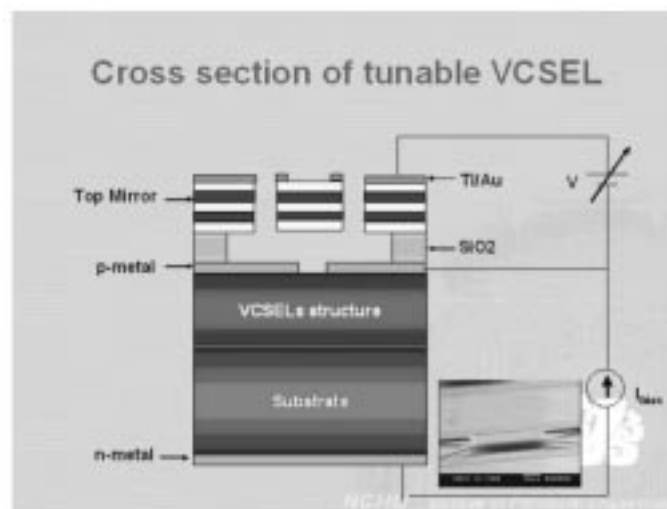


Fig. 5. Schematic of VCSEL laser fabrication.

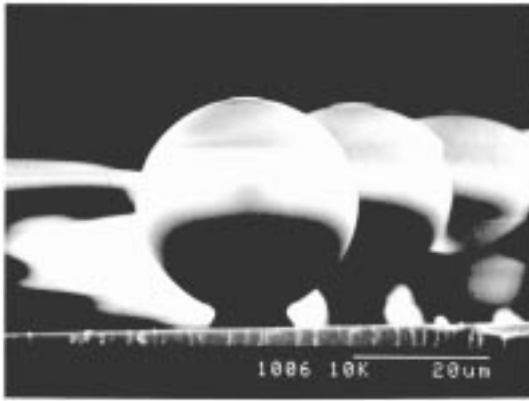


Fig. 6. SEM micrograph of the micro-ball lens array using the heat reflow process with two polymer layers.

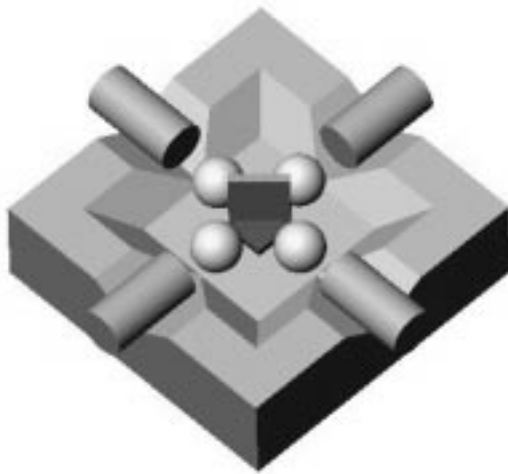


Fig. 7. Schematic 3-D cross-section view of the novel coupling platform.

source with a centred wavelength of 635 nm and a thermal expanded cord (TEC) with wider opening were used to detect the light and measure the coupling efficiency. The laser and fiber were placed on both sides of the micro-ball lens. The light beam can be coupled directly into the fiber through the micro-ball lens. The maximum coupling efficiency is approximately 63% when the fiber is placed away from the micro-ball lens surface at 9 μm . This measurement result provides for a high coupling efficiency using the micro-ball lens.

The optical switch is an important component in various optical communications applications, especially in the field of optical fiber networks. A large quantity of passive optical components is required in local area networks (LAN). An out-of-plane electrostatic-driven micro-optical switch design, fabrication, and performance evaluation was presented by the students. This novel optical switch consists of V-groove self-alignment and a self-latching vertical mirror suspension diaphragm. This design reduces the large motion area required in in-plane micro-optical switches, the difficulty of micro-assembling the fiber to the vertical mirror distance and the mirror's surface roughness. Self-parking is accomplished using a mesa at the intersection of two V-grooves designed to reduce the mechanical bounce in the vertical mirror which increases the actuator dynamic response during the motion. The micro-mirror is located on a membrane suspended by four cantilever beams and driven by an electrostatic force. The membrane and cantilever beams are made of polyimide, which produces large elongation and large displacement. Polyimide is a promising

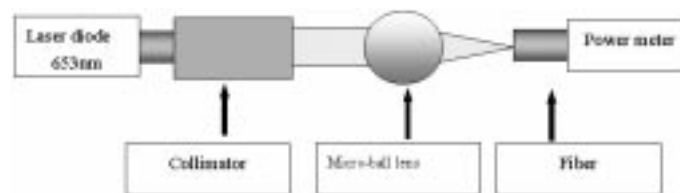


Fig. 8. Experimental coupling measurement setup.

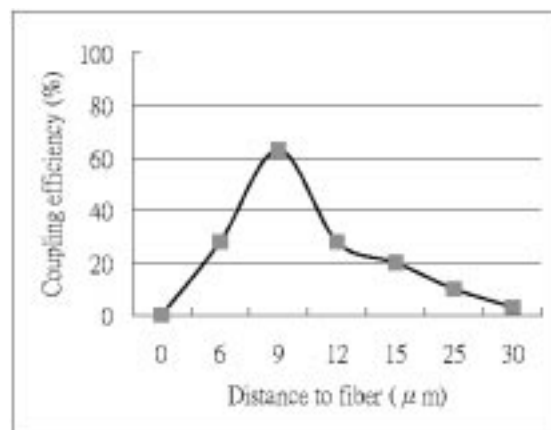


Fig. 9. Coupling efficiency based on the distance from the micro-ball lens surface to fiber.

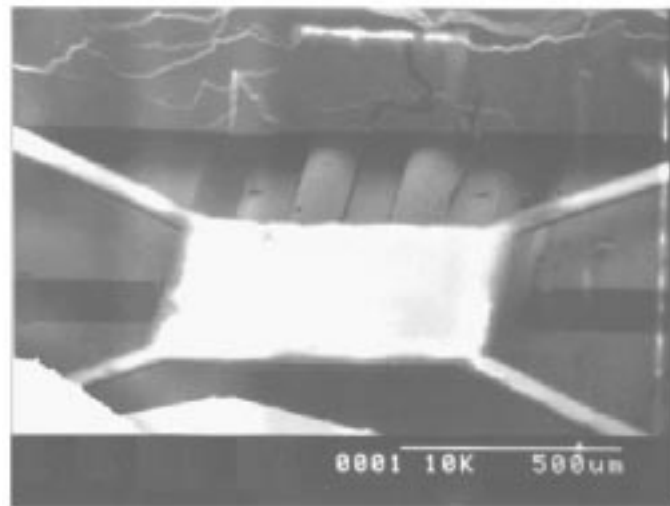


Fig. 10. SEM micrograph of the 2×2 out of an plane micro-optical switch.

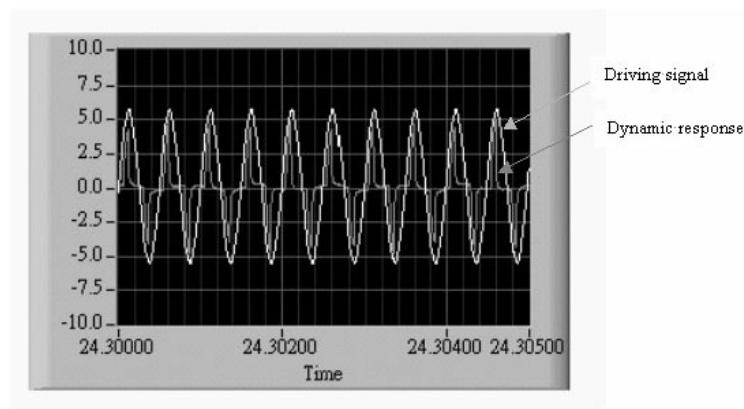


Fig. 11. The measured input signal waveform and optical dynamic switch response.

material for monolithically integrating micro-actuator array systems onto single silicon chips.

Micro-optical switches sized 2×2 and 4×4 were successfully fabricated by the students as shown in Fig. 10 [13]. The out-of-plane micro-optical switch consists of a suspension diaphragm, a vertical mirror and a self-parking fiber. The vertical mirror requires an extraordinary smooth surface for high reflectivity. The mirror surface roughness was improved using a thick SU-8 photoresist photolithography and Au sputter deposition with a thickness of 170 nm. The SU-8 vertical mirror was tilted 45° in the sputter process for each side mirror coating. The vertical mirror sidewall was measured using AFM. The vertical mirror has a surface roughness below 20 nm rms. A single-mode fiber laser beam was focused and collimated onto the vertical mirror at a height of $75 \mu\text{m}$. The reflected light was redirected and measured using a power meter. The reflectivity of the gold film mirror was higher than 85% for wavelength of 1310 nm. This vertical mirror is adequate for micro-optical switch applications. The out-of-plane micro-optical switch is electrostatically driven. An actuator voltage of 100 V is needed for 2×2 or 4×4 switches. The suspension

diaphragm displacement is $48 \mu\text{m}$ at 100 V. The optical switch dynamic response is shown in Fig. 11. The driving voltage is shown at the top waveform and the dynamic signal is shown at the bottom waveform. From the dynamic signal waveform, 2 KHz can be observed in Fig. 11.

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CONCLUSION

Microfabrication technologies play essential roles in the IT industry. It is therefore important to educate students having the ability in this field in order to face the industrial need. In this paper, we presented a curriculum that intending to cultivate the students having both theoretical insight and fabrication capability. The course design concept and support laboratories are described.

Some of the students' learning outcomes are presented. It is shown that students can use the knowledge they learned and create innovative microfabrication processes and industrial-level communication systems. In general, we believe

that our program is successful and achieves the educational goal set at the beginning of this program. However, a program refinement program based on opinions from other institutions and industries is still needed.

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