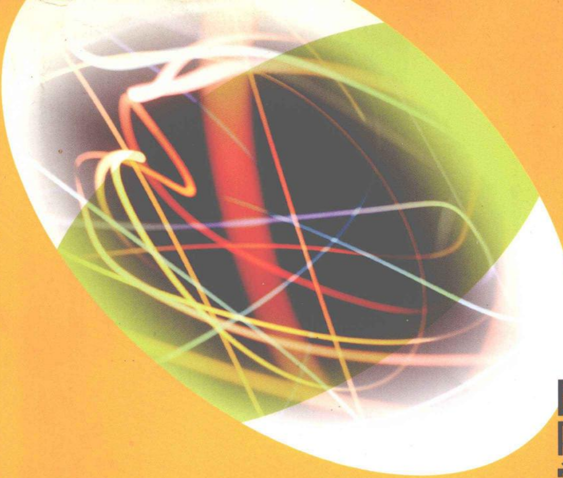
Proceedings of International Symposium on Advances and Trends in Fiber Optics and Applications

『纤维光学发展现状与未来趋势』国际学术研讨会论文集



ATFO 2004

October 11~15, 2004, Chongqing University, Chongqing, China

General Chair: Yunjiang Rao
Co-Chairs: G. D. Peng
K. T. V. Grattan
Qian Mao

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饶云江　彭刚定　主编

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内容简介

“纤维光学发展现状与未来趋势”论文集覆盖了近年来纤维光学领域发展的最新进展。其主要内容包括：光波导理论与设计、光纤有源和无源器件、光纤通信系统、特种光纤、光纤传感器等。本次会议邀请了数十位纤维光学领域的知名专家到会做特邀报告，其中包括 P. L. Chu 教授、J. Love 教授、M. Sceats 教授等，本论文集对未来纤维光学的发展提供了一个有价值的参考。

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Preface

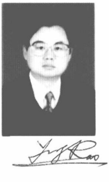
This proceedings contain summaries of papers presented at the International Symposium on Advances and Trends in Fiber Optics and Applications (ATFO 2004), Which was held on October on 11 ~ 15, 2004 in the beautiful mountain city, Chongqing, China. This meeting covers a number of key issues concerning recent progress in Fiber Optics, including optical waveguides theory and design, fiber-optic passive and active components, specialty fibers, and fiber-optic sensors. The goal of this meeting is to provide an opportunity for scientists and researchers in the field of Fiber Optics to discuss recent advances and future trends in this important area. In particular, this meeting is held in the time of the recovery of the optical fiber communication industry.

This proceedings include twenty-six invited papers, four of them presented in an opening plenary session and twenty others dispersed throughout two invited papers sessions, providing up-to-date descriptions of key areas of Fiber Optics by experts from all over the world. The four invited papers from the opening session describe important advances in main-stream research directions, such as fiber Bragg gratings, long-period fiber gratings, integrated optical circuits based on nanostructures. The program for ATFO 2004 also includes 39 contributed papers. These papers are divided into two sessions, namely optical fiber communication and optical fiber sensing.

One of the highlights of ATFO 2004 is the China-Australia Photonics Workshop to be held in conjunction with ATFO 2004. A number of leading scientists from Australia and China provide a series of interesting presentations, including photonics research and development in Australia, special optical fibres and photonic component technologies, polymer optical fibres and components, fiber-optic sensors *et al.*

We would like to thank the members of both the Advisory Committee and the Program Committee for their assistance in preparing for this symposium. We would also like to thank local organizing committee members for making this symposium successful.

We hope that you enjoy not only the symposium but also the famous Three Gorges.



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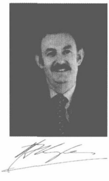

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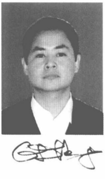

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Advances in Fibre Bragg Gratings and Applications

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Abstract: Fibre Bragg Gratings (FBGs) can now be fabricated with extremely low phase and amplitude noise. By using a technique that allows such FBGs to be produced with control of amplitude and phase along the grating, novel applications-specific FBGs can be designed and fabricated. In telecommunications, such FBGs can be used for multichannel (~80) DWDM achromatic dispersion compensators, and vestigial sideband filters, and narrow linewidth fibre lasers. In photonic signal processing, high performance microwave filters and delay lines can be made by combining FBGs with other optical components such as amplifiers. In sensor networks, FBGs can be designed with sensitivies from picostrains and millistrains, and strain gradients, for deployment in sensor networks with many FBGs, enabled by the very low out-of-band reflections. The presentation will discuss the evolution from 1-d FBGs to 2-d holographic diffractive structures.

Key words: Fibre Bragg Gratings, dispersion compensators, vestigial sideband filters, fibre lasers, strain sensors

Optoelectronics Research in Hong Kong

Pak L Chu
Optoelectronics Research CentreCity University of Hong Kong, China

Abstract: The photonics research activities in the universities and government institutions in Hong Kong are reviewed. Although such an activity has a relatively recent origin, the hard-working researchers here has made significant contributions. It is playing the leading role in photonics research in the southern part of China and will supply the need to the blossoming photonics industry in the neighbouring city, Shenzhen, the photonics valley of China.

1. Introduction

The optoelectronics research in Hong Kong has blossomed in the past ten years. Before then, only several people in different universities worked independently on some areas, mostly theoretical. This was because, before 1994, only two universities, the University of Hong Kong and the Chinese University of Hong Kong, were well-established, with the newly-established Hong Kong University of Science and Technology in its infancy. Since 1994, the government converted the then existing institutions of high learning in universities status. These are: Hong Kong Polytechnic University, City University of Hong Kong, Baptist University of Hong Kong and Lingnam University. Several years ago, a new private university, the Open University of Hong Kong, was established with the expressed purpose of offering distance learning education. In the past four years, the government also took an active part in encouraging the photonics industry in Hong Kong. Two notable achievements are the establishment of the Hong Kong Science and Technology Park (HKSTP) and the setting up of the Applied Science and Technology Research Institute (ASTRI). In less than three years since its formation, ASTRI has already spun off a photonics company specializing in photonic packaging. HKSTP erected a new six storey building dedicated as its Photonics Centre in late 2003 and invited Hong Kong photonic companies to set up their offices and research laboratories there. In less than six months, all the available space has been occupied by these companies. Many are on the waiting list.

As for in the universities, strong photonic research groups exist in four of them. They are the City University of Hong Kong (CityU), the Chinese University of Hong Kong (Chinese U), the Hong Kong Polytechnic University (PolyU), and the Hong Kong University of Science and Technology (UST). There is also some tacit understanding that they do not try to overlap each other's research areas. Very briefly, CityU is concentrated on optical devices, Chinese U on optical communication systems, PolyU on optical sensors and UST on nano-optical components. The purpose of this paper is to report on the latest salient photonic research activities of each institution.

2. The Optoelectronics Research Centre, City University of Hong Kong

The Optoelectronics Research Centre (ORC) in the City University of Hong Kong has the longest history. It was officially established as one of the university research centers in 1997. However, a strong research group on optical waveguides and optical fibres already existed in the Department of Electronic Engineering at least five years before then. At present, the research activities of ORC may be categorized into six areas: (1) Optical Waveguide Devices, (2) Optical Fibre Devices, (3) Optical Transmission, (4) Optical Sources, (5) Optical Materials, and (6) Optical Signal Processing.

To be in tune with the theme of this conference, I will describe some of the recent research work of ORC in the first three areas, i. e. optical devices based on waveguides and fibres and pulse transmission optical fibres.

2.1 Optical Waveguide Devices

The following devices are being studied in ORC:

(1) Zero-birefringence Polymer Waveguides

The form birefringence in a rectangular waveguide can be cancelled by the material birefringence of the polymer used to form the waveguide. We have found that benzocylcobutene (BCB) is the right material to use [1]. As a result, a large number of passive and active polarization-insensitive devices, including zero-birefringence multiple-quantum-well waveguides, Bragg waveguide gratings, waveguide directional couplers and semiconductor optical amplifiers have been designed [2]-[5].

(2) Fabrication of Polymer Optical Waveguide and Grating by Means of Electron Beam Direct Writing

ORC is equipped with electron beam lithographic facilities enabling them to fabricate planar optical devices with nanometer resolution. One of its features is that no mask patterning is required. The device structure is stored in the computer controlling the movement of the electron beam. An example of its application is in the fabrication of polymer optical waveguide and gratings [6], [7]. In this case, a layer of polymer, Norland Optical Adhesive 61 (NOA61), is firstly deposited on a substrate to form the cladding of the waveguide. It has a refractive index of 1.575. Another layer of polymer, Novolak Resin (ENR) is then deposited to form the core material. Its refractive index is 1.54. The cross-sectional dimensions of the waveguide are $6\mu m \times 2\mu m$. Because of the extremely fine etching of the waveguide walls and surface by electron beam photolithography, it has very small attenuation of 0.22dB/cm at 1310nm and 0.48dB/cm at 1550nm.

(3) Long-period Gratings in Polymer Waveguides (LPWG)

An ion-exchanged waveguide of 2-cm long was first formed on a BK7 glass [8]. A corrugated grating with a pitch of 102μm was introduced on the waveguide surface by reactive ion etching (RIE). The grating was finally covered with a layer of epoxy, which had a thickness of 4μm. The resonance wavelength can be thermally tuned linearly over the C + L band (1520 ~ 1610 nm) with a temperature control over a range of only ~10 ℃ [8], [9]. Both the wavelength-tuning range (~90 nm) and the temperature sensitivity (~9nm/℃) exceed those achieved with LPGs in fibres.

(4) X-Junction Polymer Optical Waveguide Switch

ORC has developed a truncated X-junction optical switch which allows the branching angle to be as large as 1.0° without compromising the cross-talk [10], [11]. A metallic thin film heater is incorporated into the exit arm of the broad waveguide. When electric current is introduced into the heater, it changes the refractive index of the waveguide so that light can be switched from the broad waveguide to the narrow waveguide. The design is very useful for space-division switching in future broadband photonic networks. It finds applications in wavelength-division multiplexing optical path cross-connect systems, inter-module connectors, and protection switches. The simulated crosstalk of the switch in the "OFF" and "ON" state are −28dB and −26dB respectively. Polymeric material benzocyclobutuene was used to fabricate the design on silicon substrate. The switching electric power required is 145mW and the average switching time is approximately 180μs. This switch also operates over a wide wavelength range, from C band to L band. The polarization dependent loss is less than 0.5dB.

(5) **Vertical Optical Waveguide Splitter and Switch**

ORC recently developed optical splitters and switches based on vertically-coupled polymer waveguides with design. As a splitter, its TE and TM can achieve an extinction ratio of 15.7dB and 27.5dB respectively. The polymers used are based on the material ZP49 and ZP51 supplied by Zenphotonics Korea. If an electrode is deposited over waveguide WG1, the device can be turned into a thermal optical switch [12]. It has been shown that the switching ratio as high as 23dB. More importantly, its operating bandwidth covers the whole of C-band.

(6) **Erbium Doped Waveguide Amplifiers (EDWA)**

Recently EDWA was constructed with Li^+ based Er^{3+}-Yb^{3+} codoped phosphate glass as the starting material [13]. It contained more than 10 mol% Li^+ ions with Er^{3+} and Yb^{3+} concentration of about 2wt% each. The Ag^+-Li^+ ion-exchange process together with the photolithography technique were used to form optical waveguides of different channel widths, 4, 6, 8, 10 and 12μm. The 4- and 6-μm channels are single-moded at 1550nm while the 8- and 10-μm channels are two moded and the 12μm channel is 3 moded. It has been found that at pump power of 110mW, the net gain can be as high as 3.3dB/cm at 1535nm. This figure is larger than 2.3dB/cm obtained from ion-exchanged silicate glass waveguide amplifier but less than the 4.1dB/cm obtained from sputtered technique. However, the sputtering technique is more complicated.

2.2 Optical Fibre Devices

(1) **Bragg-Fibre-Grating Current Sensor**

Fibre Bragg gratings (FBGs) are written routinely in the ORC laboratory with the phase-mask technique using an excimer laser (248nm) as the UV source. They have developed an FBG-based electric-current sensor [14] in that, half of the grating is bonded onto a magnetostrictive material, Terfenol D, and the other half on a non-magnetostrictive material, Monel 400. When this grating is placed in a magnetic field created by an electric current, the part of the grating bonded onto Terfenol D is stretched while the other part is not. Thus, the reflection spectrum of the whole grating is split into two spectra and the current can be determined by measuring the amount of light reflected from the spectra. Because Monel 400 and Terfenol D have almost identical thermal expansion coefficients, a change in temperature does not cause the reflection spectrum of the grating to split and, therefore, does not affect the electric current measurement. In fact, a similar principle has been applied to a temperature-compensated FBG-based vibration sensor [15].

(2) **Long-period Fibre Gratings (LPFG) and Applications**

Gain flattening of EDFAs can be realized with carefully designed LPFG filters to suppress the peaks in the EDFA gain profiles. Fixed LPFG-based gain equalizers are already commercially available. However, dynamic gain flatteners that can provide adjustments for different amplifiers under changing operating conditions are more desirable. ORC have demonstrated the principle of a dynamic gain flattener using multiple tunable LPFCs [16]. The same technique has also been used for the compensation of polarization fluctuations in the EDFA gain [17].

In general, the resonance wavelength of an LPFG is sensitive to the temperature [18], the strain along the LPFG, and the refractive index of the surrounding medium [18]. Measurement of the shift of the resonance wavelength in response to a change of these physical parameters forms the basis of LPFG sensors. The ability to measure refractive index conveniently is a unique feature of LPFGs, which allows the development of LPFG-based biochemical sensors. For refractive-index measurement, however, the temperature effect must be eliminated. Recently, ORC has proposed a flexible and inexpensive method of reducing the temperature sensitivity of a bare LPFG [19]. The method is based on canceling the temperature with the bending effect by mounting a bent LPFG on a material with a suitable thermal expansion coefficient. With this method, the temperature sensitivity of the resonance wavelength of an LPFG can be reduced by two orders of magnitude from

-0.933 nm/℃ to 0.008 nm/℃. The sensor has been used for the measurement of the NaCl concentration in a sodium chloride solution.

(3) Segmented Cladding Polymer Fibre

Recently, Chiang and Rastogi of the ORC invented a new fibre structure, which is known as the segmented cladding fibre (SCF) [20]. The fibre has a uniform core of high refractive index and a cladding with alternate regions of high and low index in the azimuthal direction. The SCF can offer single-mode operation over an extended range of wavelengths or provide single-mode operation in the S + C + L band with an ultra-large core area [21]. In this aspect, the SCF behaves like a photonic crystal fibre or a holey fibre. Unlike a holey fibre, however, the SCF uses a small index contrast (since there are no air holes) and, hence, has potentially low polarization-mode dispersion, which is essential for high-bit-rate transmission. In collaboration with the University of New South Wales, such a 4-segment fibre has been fabricated using PMMA polymers [22].

(4) Generation of Wavelength-tunable Picosecond Pulses

ORC recently discovered that two close wavelengths can be selected from the same mode of a Fabry-Perot Laser Diode (FP-LD), and demonstrated the generation of stable dual-wavelength picosecond pulses with a close wavelength separation from a self-seeded FP-LD and a tunable FBG [23]. By bending half of the FBG mounted on a beam, the wavelength separation of the pulses can be tuned from 0.21 nm to 0.44 nm at a pulse rate of ~ 2 GHz [23].

2.3 Optical Transmission

(1) Secure Communication system based on Chaos generated from fibre laser

While chaos communication systems per se have been studied extensively in recent years, there are still many problems to be solved before they can be used in practice. In ORC, two related problems have been studied: (1) the effect of dispersion and nonlinearity of the transmission fibre on the synchronization of the chaoses, and (2) the introduction of WDM technique to the system.

In the first problem [24], three different transmission fibres were considered: (a) conventional single mode fibre with attenuation 0.2dB/km at 1550nm, dispersion $-20ps^2/km$ and Kerr nonlinearity 1.3/W/km, (b) dispersion-compensated fibre consisting of a conventional single mode fibre and a dispersion-compensating fibre with dispersion $100ps^2/km$ and Kerr nonlinearity 3.5/W/km, and (c) dispersion-shifted fibre with attenuation 0.2dB/km at 1550nm, dispersion $-0.1ps^2/km$ and Kerr nonlinearity 1.5/W/km. In all three cases, the amplifier noise figure is assumed 5dB.

For the conventional fibre specified in case (a) barely acceptable BER is obtained for transmission distance at 60km at bit rate 0.78Gb/s. Higher bit rate or longer distance induces unacceptable BER. For cases (b) and (c), there exists an optimum transmission power which can balance the effect of the amplifier noise against the fibre nonlinearity. For example, the smallest BER can be achieved at P_{av} = 3dBm for a dispersion-compensated fibre and at P_{av} = 2dBm for a dispersion-shifted fibre. Since the amplifier gain at spacing length 60km are 15dB and 12dB for the two cases respectively, the dispersion-compensated fibre suffers more noise effect. However, with the increase of P_{av}, the system performance deteriorates more rapidly for the DSF case, especially when the encoded message is at higher bit rate BR_3. This is not surprising since in the case (b), the transmitted field is broadened by the SMF and then compressed by the DCF; while in case (c) it is only slightly broadened due to the small dispersion of DSF. Thus fibre nonlinearity effect is more serious in the DSF.

ORC has also developed a technique in generating two chaoses each carried by a different wavelength [25]. This is an attempt to develop a WDM system in the chaos communication technique. Instead of using a fibre ring laser for chaos generation, two pairs of gratings in a length of Erbium-doped fibre were fabricated thus forming two resonant cavities. One pair has a Bragg wavelength 1550nm and the other 1540nm. The 980nm pump is modulated at a frequency about 6kHz. Simultaneous generation of chaoses at these two wavelengths are observed at the output.

(2) Soliton Trapping in Fibre Bragg Gratings

Recently, there arose an interest in slowing down an optical soliton in a fibre Bragg grating. This approach is reasonable because a grating is a periodical structure and it is well known that an electromagnetic wave (soliton is an electromagnetic pulse) is slowed down by such a structure. The degree of slowing down depends on the parameters of the soliton and also on the parameters of the grating. It has been shown experimentally a soliton could be slowed down to 50% of its original speed in a fibre without grating.

ORC's interest, however, is to study how to stop the soliton from moving within the grating. Three approaches have been studied in this regard. In the first, they have developed a theory of trapping a soliton in the fibre Bragg grating by means of a local defect [26]. They found that in order for the trapped soliton to remain stable indefinitely, its normalized energy must be equal to 0.5π and the defect strength (for example, the normalized change of reflectivity of the grating) is equal to 0.08. On the other hand, a moving soliton can only be trapped when its velocity in the grating is already 20% of its velocity in the fibre without grating. Furthermore, the normalized soliton energy should also be 0.5π and normalized defect strength 0.2.

In the second approach, they considered another situation where instead of a defect, a localized gain in the grating is used to trap the soliton [27]. This is towards a more realistic situation. If the soliton is trapped by a defect, the fibre loss will lead to the destruction of the soliton. Hence the soliton energy should be maintained by introducing some gain into the fibre grating. The local gain can be provided, for instance, by a short segment of Erbium-doped fibre within the grating. Through this study, it was found that, provided that the gain thus introduced is sufficient to cancel of the loss of the grating, the soliton is trapped at the position of the local gain if its normalized energy is again equal to 0.5π.

In the third approach, they also studied the trapping of solitons in a grating, not by means of local defect or local gain as before, but by allowing two solitons collide with each other head-on [28]. It was found that if the collision velocities of the two solitons are sufficiently small, say about 0.2 of the maximum velocity in the fibre without grating, the two solitons will merge into one and remain in the center of the grating provided that they are in phase. However, the grating discussed here must be chirped so that the soliton colliding velocity is 0.2. The situation is somewhat relieved if we allow the two solitons to circulate in a fibre loop containing the Bragg grating in opposite directions so that they suffer multiple collisions. Under this situation, the largest initial soliton velocity admitting merger increases from 0.2 to 0.4.

3. Chinese University of Hong Kong

The photonics research in the Chinese University of Hong Kong has been scattered mainly within the department of information engineering and the department of electronic engineering. In 2002, they established the Institute of Optical Science and Technology and invited the world-renown scientist, Professor Chinlon Lin, to be its director. They concentrate their research in three areas (1) Wavelength and Format Conversion, (2) Optical Performance Monitoring, and (3) WDM Optical Access Network.

Wavelength and Format Conversion:

(1) By Injection Locking

The technique of dual-wavelength injection locking of a Fabry-Perot (FP) laser diode had been developed some time ago in the Chinese University [29] and is a potentially low cost technique for all-optical wavelength