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RESEARCH ARTICLE

Fiber optical WDM multiplexers/demultiplexers with low bending losses

Dmitry A. Ivanov @

MIREA – Russian Technological University, Moscow, 119454 Russia
@ *Corresponding author, e-mail: d.ivanov@tmvos.com*

Abstract
Objectives. One of the topical tasks in the development of radio electronic systems for various purposes is a sharp increase in the volume and data transfer rate between the elements of the system. This problem is most successfully solved using fiber optic technology, which has no alternative to meet a number of indicators. The use of optical fibers (OF) as a physical medium made it possible to transfer large information flows over considerable distances. Increasing the capacity of communication systems is pushing manufacturers to develop new OF brands with improved optical and operational characteristics, which makes it possible to improve various optical components that use an OF as an active information transmission medium. The dual-channel single-mode wavelength division multiplexing (WDM) multiplexers/demultiplexers, which are one of spectral selective splitters types, are most widely used in fiber-optic communication systems. Among the advantages of WDM, it is worth to note the transmission of a large amount of information over one OF by the arrangement of channels at different wavelengths and the ability to transmit signals of several wavelengths simultaneously in both directions via one OF that do not interact with each other (duplex communication). During operation, WDM multiplexers can be subjected to various external influences that affect the operation and stability of the device parameters. Currently, there are no data on the effect of OF bending on the optical characteristics of WDM multiplexers. In this regard, it is important to study this dependence, which includes measuring the parameters of optical isolation and insertion loss. The purpose of the study is to work out the manufacturing technology and investigate the manufactured WDM multiplexers based on certain types of bend-resistant OF.
Methods. For the formation of two-channel WDM multiplexers, the technology of fused biconical tapering was used, which makes it possible to achieve low insertion loss along with a high degree of channel isolation in the wide temperature range.
Results. In the paper, the possibilities of manufacturing fiber multiplexers based on bend-resistant fiber Corning SMF-28 Ultra were discussed. The results of manufacturing and studying the experimental samples of WDM multiplexers optical characteristics were presented. It was established that the use of SMF-28 Ultra quartz fiber made it possible to significantly reduce the deviation of the channel optical isolation in the event of mechanical stresses in the multiplexers OF structure.
Conclusions. The possibility of creating two-channel multiplexers with low bending losses and optical isolation up to 20–22 dB was experimentally shown. Possible mechanisms of the influence of the multiplexer fiber twisting on the optical isolation of channels were considered. The results obtained showed that when mechanical stresses in the fused structure of the multiplexer occur, the change in the optical isolation coefficient at two operating wavelengths does not exceed 1 dB.

Keywords: fiber-optic communication systems, bend-resistant optical fiber, multiplexer, WDM multiplexer, fused biconical taper technology, coupling region

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НАУЧНАЯ СТАТЬЯ

Волоконно-оптические WDM-мультиплексоры/демультиплексоры с малыми изгибными потерями

Д.А. Иванов @

МИРЭА – Российский технологический университет, Москва, 119454 Россия
@ Автор для переписки, e-mail: d.ivanov@tmvos.com

Резюме
Цели. Одной из актуальных задач развития радиоэлектронных систем различного назначения является резкое увеличение объема и скорости передачи информации между элементами этих систем. Такая задача наиболее успешно решается с использованием средств волоконно-оптической техники, не имеющих альтернативы по ряду показателей. Применение оптических волокон (ОВ) в качестве физической среды позволило осуществить передачу больших потоков информации на значительные расстояния. Увеличение пропускной способности систем связи подталкивает производителей к разработке новых марок ОВ с улучшенными оптическими и эксплуатационными характеристиками, что позволяет усовершенствовать различные оптические компоненты, которые используют волоконный световод в качестве активной среды передачи информации. Наиболее широко используемыми в волоконно-оптических системах связи (ВОСС) являются двухканальные одномодовые WDM-мультиплексоры/демультиплексоры, представляющие собой вид спектрально-селективных разветвителей. Среди преимуществ WDM-мультиплексирования стоит отметить передачу большого объема информации по одному ОВ за счет организации каналов на разных длинах волн, возможность передавать по одному ОВ одновременно в обоих направлениях сигналы нескольких длин волн, которые не взаимодействуют друг с другом (дуплексная связь). В процессе эксплуатации WDM-мультиплексоры могут подвергаться различным внешним воздействиям, влияющим на работу и стабильность параметров устройства. В настоящее время отсутствуют данные по влиянию изгибов ОВ на оптические характеристики WDM-мультиплексоров. В связи с этим актуальным является исследование данной зависимости, которое включает в себя измерение параметров оптической изоляции и вносимых потерь. Цель работы – отработка технологии изготовления и исследование изготовленных WDM-мультиплексоров на основе определенных видов ОВ, устойчивых к изгибу.
Методы. Для формирования двухволновых WDM-мультиплексоров использована технология сплавной биконической вытяжки (FBT), позволяющей достичь низких вносимых потерь одновременно с высокой степенью изоляции каналов в широком диапазоне температур.
Результаты. В работе рассмотрены возможности изготовления волоконных мультиплексоров на основе изгибоустойчивого волокна Corning SMF-28 Ultra. Представлены результаты изготовления и исследования оптических характеристик экспериментальных образцов WDM-мультиплексоров. Установлено, что применение кварцевого волокна SMF-28 Ultra позволило существенно снизить девиацию оптической изоляции каналов при возникновении механических напряжений в световодной структуре мультиплексоров.

Выводы. Экспериментально показана возможность создания двухволновых мультиплексоров с малыми изгибными потерями и оптической изоляцией до 20–22 дБ. Рассмотрены возможные механизмы влияния скручивания волоконных выводов мультиплексора на оптическую изоляцию каналов. Полученные результаты показывают, что при возникновении механических напряжений в сплавленной структуре мультиплексора изменение коэффициента оптической изоляции на двух рабочих длинах волн не превышало 1 дБ.

Ключевые слова: волоконно-оптические системы связи, изгибоустойчивое оптическое волокно, мультиплексор, WDM-мультиплексор, FBT-технология, область связи

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INTRODUCTION

Modern fiber-optic communication systems (FOCS) are characterized by a constant increase in throughput, improvement in the optical components performance, and the ever-increasing introduction of fiber-optic devices into special equipment. This imposes increased requirements on the reliability, miniaturization, and performance of FOCS components [1].

In the recent years, FOCS with wavelength division multiplexing have been actively used in various telecommunication systems. To implement such systems, special passive optical devices are often used, such as fused wavelength division multiplexing (WDM) multiplexers/demultiplexers, designed to combine and separate several information signals with wavelengths of 1.31 μm and 1.55 μm and transmit them over a single optical fiber (OF) [2]. Such devices have been used in the market for a long time and have proven themselves due to a fairly high level of performance and low cost. Multiplexers currently produced by a number of leading companies and enterprises are usually made from standard Corning SMF-28e+ category G.652.D fiber, which is actively used in urban and access networks. However, such a fiber has one significant drawback. This is an increase in losses caused by macrobends, which degrade the data transmission and reception quality [3–5]. Therefore, multiplexers based on this fiber are also affected by the fiber bending and, as a result, the deterioration of their optical characteristics.

This work analyzed the issues of manufacturing technology and the possibility of forming fused multiplexers based on bend-resistant single-mode Corning SMF-28 Ultra[1] fiber and presents the results of manufacturing and studying the optical characteristics of WDM multiplexers experimental samples.

CORNING SMF-28 ULTRA QUARTZ BEND-RESISTANT FIBER

Corning SMF-28 Ultra single-mode fiber with improved optical attenuation and bending loss resistance exceeding the requirements of ITU-T G.657.A1 makes it possible to upgrade existing fiber optic telecommunications devices, in particular, two-channel WDM multiplexers, whose light guide structure is sensitive to various influencing factors.

Figure 1 shows bend attenuation for standard G.652.D fiber and bend-resistant SMF-28 Ultra fiber [6].

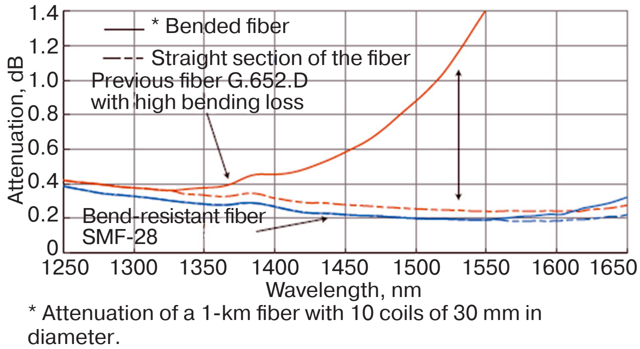

Fig. 1. Bend attenuation gain in standard G.652.D fiber and bend-resistant SMF-28 Ultra fiber

Figure 1 shows that at longer wavelengths, when the optical signal is less dependent on the core of a single-mode OF, the bending losses in the G.652.D fiber increase significantly compared to the bend-resistant SMF-28 Ultra fiber.

[1] SMF-28® Ultra Optical Fibers. URL: https://www.corning.com/ru/ru/products/communication-networks/products/fiber/smf-28-ultra.html. Accessed June 7, 2021 (in Russ.).

CORNING SMF-28 ULTRA WDM MULTIPLEXER MANUFACTURING TECHNOLOGY

The manufacturing technology of fiber optic two-channel WDM multiplexers with low bending losses is based on the fusion of two bend-resistant SMF-28 Ultra fibers with simultaneous stretching of the branching section to obtain a smooth biconical taper necessary for effective waveguide coupling between the fibers (fused biconical taper (FBT) technology) [7].

The method of creating a single-mode WDM multiplexer is illustrated in Fig. 2 [8].

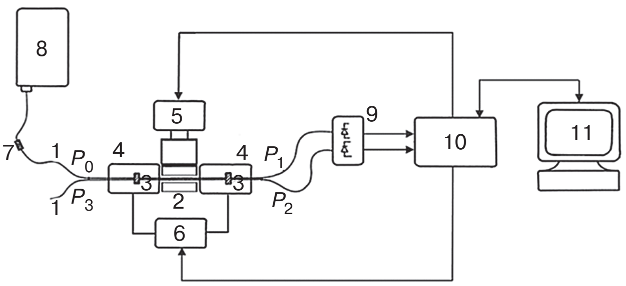

Fig. 2. Structural diagram of the device for the manufacture of fused WDM multiplexers:
(1) SMF-28 Ultra OFs,
(2) high-temperature heater,
(3) fiber clamping units,
(4) movable carriages,
(5) heater power supply,
(6) electric drive unit,
(7) place for fusing the pigtail with SMF-28 Ultra fiber,
(8) light source,
(9) photodetector,
(10) control unit,
and (11) personal computer

Sections of SMF-28 Ultra fibers prepared in advance and cleaned at a length of ≈35 mm from the protective outer coating were interconnected by twisting around the longitudinal axis for one full turn (Fig. 3), forming a branching section for forming a multiplexer, fixed on carriages and placed into the heater.

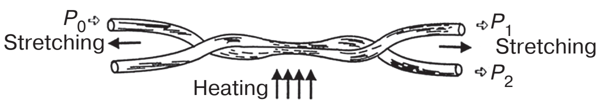

Fig. 3. Branching section of two twisted fibers

During the manufacture of the multiplexers, the current values of the radiation power P_1 and P_2 coming from the output channels of the multiplexer to the photodetectors of the computerized measuring system were monitored [9]. The process was terminated when a certain length of the coupling region (z) was reached, which is necessary for the spectral selection of two wavelengths (Fig. 4) [10, 11].

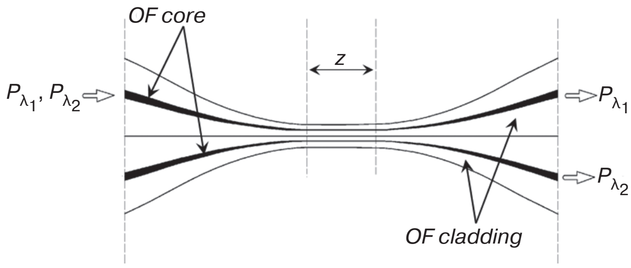

Fig. 4. Schematic representation of the FBT multiplexer

One of the main characteristics of fused WDM multiplexers is the insertion loss A_{in} and the isolation coefficient K_{is}, which determines the level of signal attenuation in those channels, in which this signal is not the main one. For this device, the above parameters are defined by the following expressions:

$$A_{in} = 10\lg\frac{P_0}{P_i};\; K_{is} = 10\lg\frac{P_0}{P_j};\; j \neq i = 1,2, \qquad (1)$$

where P_0 is the optical power in the input channel at wavelength λ_i; P_i is the optical power at the output of the ith (main) channel at wavelength λ_i; P_j is the optical power in the jth (non-fundamental) channel at wavelength λ_i.

The most important requirements for optical splitters for WDM systems are to provide a given splitting ratio between channels with minimal deviations from the given value and the minimum value of insertion attenuation over the entire operating spectral range [12, 13].

MANUFACTURING AND RESEARCH OF WDM MULTIPLEXERS

In the present work, FBT multiplexers were fabricated using a Japanese FCI-0201 facility from NTT AT with a ceramic microheater [14–16].

The method for forming light guide biconical structures is schematically shown in Fig. 5 [17].

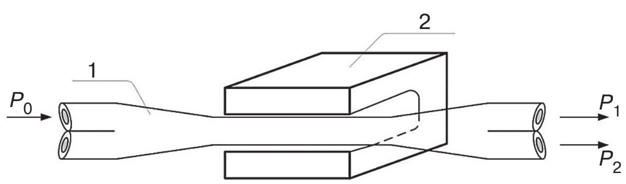

Fig. 5. Multiplexer manufacturing method: (1) SMF-28 Ultra OFs and (2) ceramic microheater

For the successful manufacture of WDM multiplexers based on SMF-28 Ultra fiber, a technology with optimal

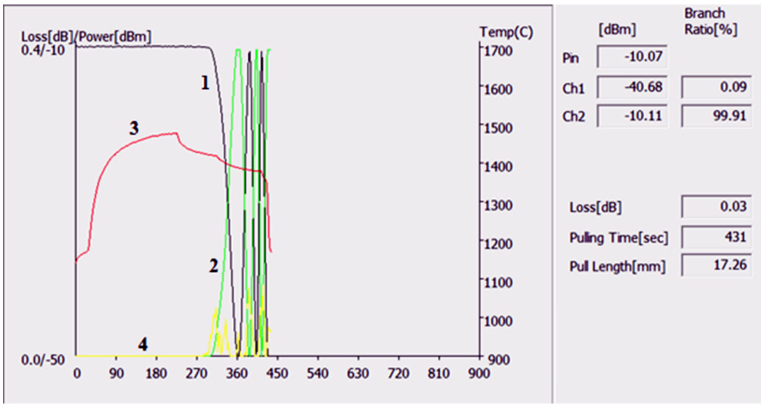

Fig. 6. The result of manufacturing the WDM multiplexer:
(1) radiation power P_1 at the output of channel Ch1,
(2) radiation power P_2 at the output of channel Ch2,
(3) heating temperature of the fiber fusion zone, and (4) insertion loss

temperature and time parameters of the process was developed. The heating temperature of the fiber fusion zone was 1500–1550°C, and the pulling speed decreased from 60 μm/s at the beginning of the process to 10 μm/s at the end.

In the process of stretching and formation of a biconical waist, the change in the radiation power P_1 and P_2 in the fiber outputs of the multiplexer was displayed, and the insertion loss for a wavelength of 1550 nm was monitored (Fig. 6). The pulling time of the sample during fusion was about 431 s. The pull length after fusion was 17.26 mm, and the total length of the multiplexer fiber structure was 53 mm. The insertion loss of the fabricated sample did not exceed 0.1 dB. The optical isolation factor of the WDM multiplexer channels was 20–22 dB.

The performance stability of WDM multiplexers under operating conditions greatly depends on their light guide structure. Various mechanical influences that a multiplexer may be subjected to during operation can lead to deformation of its biconical structure and, as a result, to a decrease in the isolation coefficient and disruption of the transmission line [18].

One of possible mechanical influences is due to the twisting of the light guide structure of the formed multiplexers that may cause the redistribution of optical power in the channels and the change in the optical isolation value. Such an effect was observed in the study of multiplexers based on the standard fiber SMF-28e+ [19].

The experiment was conducted with multiplexers manufactured based on SMF-28 Ultra bend-resistant fibers to study the effect of twisting of the fused structure on the optical isolation of channels. For this, one section (1) of the fiber leads (2) of the multiplexer on the side of the optical light source rotated around the optical axis of the biconical structure, and the other section (3) on the side of the optical power meter was fixed (Fig. 7). The distance l between sections 1 and 2 of fibers was 200 mm. During the experiment, the isolation factors were continuously measured at two operating wavelengths λ_1 = 1310 nm and λ_2 = 1550 nm.

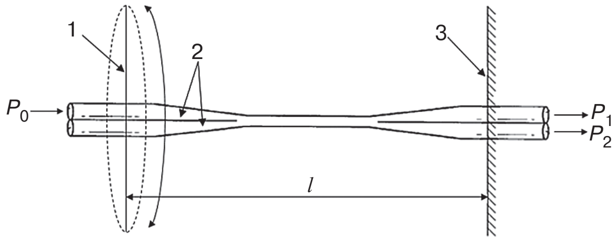

Fig. 7. Schematic representation of the twisting of the fiber structure of WDM multiplexer

As a result of the study, it was found that when mechanical stresses occurred in the fused structure of the multiplexer, the change in the optical isolation factor at two operating wavelengths did not exceed 1 dB. The use of SMF-28 Ultra quartz fibers made it possible to significantly reduce the optical isolation deviation of the channels in the event of mechanical stresses in the OF structure of the multiplexers.

CONCLUSIONS

A method for manufacturing the fused single-mode multiplexers from Corning SMF-28 Ultra fiber was presented. The optical characteristics of the fabricated samples were studied. Possible mechanisms of the influence of the multiplexer fiber leads twisting on the channels optical isolation were considered. The possibility of creating two-channel multiplexers with low bending losses and optical isolation up to 20–22 dB was experimentally shown.

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About the author

Dmitry A. Ivanov, Postgraduate Student, Department of Optoelectronic Devices and Systems, Institute for Advanced Technologies and Industrial Programming, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). E-mail: d.ivanov@tmvos.com. https://orcid.org/0000-0001-5437-7522

Об авторе

Иванов Дмитрий Александрович, аспирант кафедры оптико-электронных приборов и систем Института перспективных технологий и индустриального программирования ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). E-mail: d.ivanov@tmvos.com. https://orcid.org/0000-0001-5437-7522

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