# World's Largest Transmission Capacity with Standard Diameter Multi-core Optical Fiber—Accelerated Multi-core Fiber Application Using Current Standard Technology

## 1. Introduction

NTT and six partners, KDDI Research, Inc. (KDDI Research), Sumitomo Electric Industries, Ltd. (Sumitomo Electric), Fujikura Ltd. (Fujikura), Furukawa Electric Co., Ltd. (Furukawa), NEC Corporation (NEC), and Chiba Institute of Technology (CIT) have demonstrated the world's largest transmission capacity of 118.5 Tbit/s using a multi-core fiber with four optical paths (cores) with the same diameter as the optical fiber in current use.

Having a conventional glass diameter (125 µm) in accordance with the international standard enables us to effectively use existing optical fiber fabrication and optical connector technologies. This achievement proves that the concept of a multi-core fiber based long-haul and large capacity transmission system consisting of multiple vendor technologies is viable, and it makes significant progress in the practical use of multi-core fiber technology (**Fig. 1**).

Our objective is to introduce the standard diameter multi-core fiber by the early 2020s. We will also continue to contribute to developing a future optical infrastructure that can support various data communication demands.

This remarkable achievement was reported in early August as a postdeadline paper at the Opto-Electronics and Communications Conference (OECC 2017), the largest conference on optical communication in Asia Pacific-Rim, which was held at the Sands Expo and Convention Centre, Singapore, from July 31 to August 4, 2017. This work was partially based on work commissioned by the National Institute of Information and Communications Technology (NICT).

## 2. Research background

The worldwide spread of various mobile terminal and data services has led to a continuous increase in transmission capacity of more than 10% per year all over the world. However, the increase in capacity may not keep up with the increase in demand, a trend that may cause a capacity crunch in the currently used optical fiber by the late 2020s. Moreover, the continued expansion of the optical fiber count (i.e., the number of fibers used) and the convergence of optical wiring—particularly in datacenters and/or central offices—which is caused by the worldwide data capacity increase, would be a serious problem.

Against this background, multi-core fiber having multiple optical paths (cores) in one fiber has been investigated intensively all over the world in order to overcome the future capacity crunch and to achieve high density or space-saving optical facilities. For example, ultralarge capacity transmission experiments using a multi-core fiber with ten cores or more have been demonstrated. However, this high core count multi-core fiber usually needs a thicker glass diameter, and it requires an extreme advance in the fabrication process and further development of subcomponents. Consequently, about ten years or so is

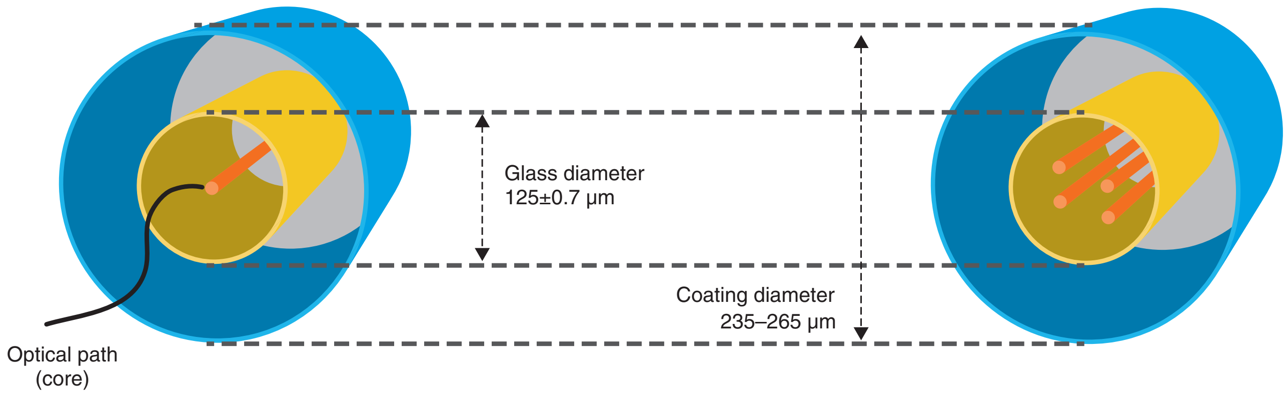


Fig. 1. Features of proposed multi-core fiber.

expected to be necessary to make the high core count multi-core fiber practical.

To accelerate the use of multi-core fiber technology, NTT, KDDI Research, Sumitomo Electric, Fujikura, Furukawa, NEC, and CIT developed a multi-core fiber with a conventional diameter in accordance with the current international standard. This makes it possible to use existing optical fiber technology even though the number of cores is limited to four or five.

## 3. Design guidelines

The fabrication process of an optical fiber starts with preparing a relatively large glass rod with a diameter of several to ten centimeters called a preform. An optical fiber is made by melting and drawing the preform while maintaining the geometrical similarity. When the glass diameter of an optical fiber is doubled (e.g., from the conventional 125 µm to 250 µm), the fabrication length obtained with the same size preform is reduced to a quarter. Therefore, the increase in the glass diameter directly affects the mass productivity of an optical fiber. The current optical communication system commonly uses a single-mode fiber (SMF) with a core diameter of about 10 µm, which can be used in the entire telecommunication wavelength region (1260–1625 nm).

We therefore aim to achieve a multi-core fiber with two features: i) respective glass and coating diameters of 125 ± 0.7 µm and 235–265 µm in compliance with the international standard of the current optical fiber, and ii) a fiber whose individual core has a similar transmission quality to that of the commonly used SMF. In a multi-core fiber, the optical signal interference between neighboring cores should be reduced sufficiently. NTT and KDDI Research revealed that four to five cores can be arranged in a 125-µm glass diameter.

Our vision of future communication traffic sees the widespread distribution of high-resolution images and video such as 4K/8K and the full-scale popularization of machine-to-machine services. The obvious assumption is that capacity demands will skyrocket. Thus, NTT has been actively pursuing a wide spectrum of studies into achieving ultralarge capacity transmission of signals exceeding 100 Gbit/s. Furthermore, with the recent increase in traffic between datacenters, greater capacity must be matched by greater cost savings.

Greater capacity is most directly achieved by using multiple bands (C band + L band etc.), which expands the usable bandwidth of the optical fiber. However, several problems arise if we attempt to transmit multiband signals by wavelength division multiplexing (WDM) over dispersion shifted optical fiber (DSF: dispersion shifted fiber) cable. The zero dispersion wavelength of DSF lies in the extended band (C band), and around this wavelength, the signal is degraded by nonlinear effects (especially four-wave mixing). The common solution, unequally spacing the signal wavelengths in the C band, degrades the wavelength utilization efficiency. This is a barrier to further capacity increases.

## 4. Multi-core transmission line composed of multiple vendor optical fibers

Sumitomo Electric, Fujikura, and Furukawa used the above design guidelines to individually fabricate multi-core fibers with four cores over 100 km in length. All the multi-core fibers developed by these companies can be used in the 1260–1625 nm wavelength region, and they have similar transmission properties to the current SMF. (For comparison, mode field diameter (MFD) at 1550 nm is 9–10 µm.)

The fabricated multi-core fibers were divided into segments 20–40 km long, and three transmission spans with a length of 104–107 km were reconstructed by splicing the multi-core fibers provided by different vendors. Satisfactory low loss characteristics comparable to the conventional SMF were achieved. The average loss of four cores in each span was 0.22 dB/km or less, including splicing losses. We applied fusion splicing to splice two multi-core fibers by melting each end. A 0.21-dB/km loss property was achieved as the average of all three spans.

These achievements indicate that our standard diameter multi-core fiber with similar transmission quality (MFD) to that of the conventional SMF will make it possible to greatly improve the productivity of the multi-core fiber made by effectively using the existing fabrication technology and knowledge.

## 5. Beyond 100-Tbit transmission

A multi-core transmission system was constructed by concatenating three spans. Three multi-core optical amplifiers fabricated by NEC, KDDI Research, NTT, and Furukawa were inserted at each end of three spans in order to compensate for the signal attenuation. Cladding pumping type multi-core optical amplifiers that were expected to reduce power consumption were used, and a 16% improvement was confirmed in this achievement. To confirm the capability of the constructed multi-core transmission line to beyond 100-Tbit/s transmission, 16QAM (quadrature amplitude modulation) based 116-wavelength division multiplexing signals were prepared, and the output signal quality after 316-km-long transmission was examined.

Fan-in/fan-out devices fabricated by NTT and Furukawa were used to input/output signals to/from each core of the multi-core fiber. Pluggable optical connectors with existing MU (miniature universal coupling)-type or SC (single fiber coupling)-type interfaces, fabricated by CIT and NTT, were used to connect the input/output end of the multi-core transmission lines and fan-in/fan-out devices. These optical connectors have rotational alignment features in order to connect the facing four cores correctly. Thus, the low loss and pluggable optical connection of multi-core structure was achieved.

Satisfactory transmission quality was confirmed in all cores and at all wavelengths. This result is the world's largest transmission capacity of 118.5 Tbit/s for a standard diameter optical fiber. These achievements reveal that multi-core fiber with a standard diameter can be used to achieve an ultralarge capacity transmission system to overcome the capacity crunch in the current SMF.

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