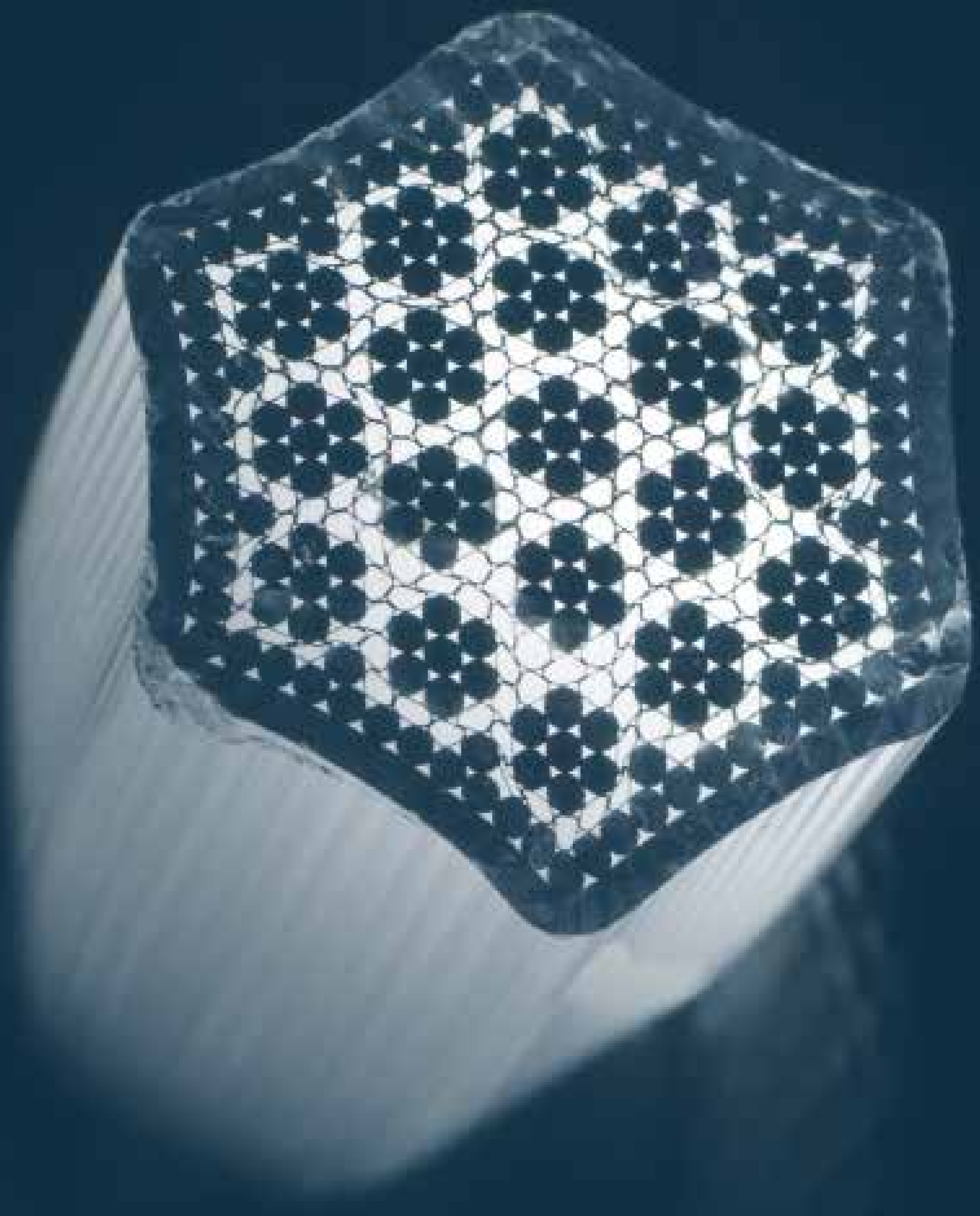

MultiCore Fiber

by InPhoTech®
INNOVATION PHOTONICS TECHNOLOGY

IS THE FUTURE OF INFORMATION CAPACITY IN DANGER?

The growth of information capacity in telecommunication systems was made possible by a series of technological breakthroughs which have taken place over the past fifty years. Since the invention of low loss silica optical fibers in the 80s, one of the turning points was the development of a method for amplifying an optical signal using **Erbium Doped Fiber Amplifiers (EDFA)**. Then, the number of channels per fiber was increased and the era of **Wavelength Division Multiplexing (WDM)** emerged. This, combined with the installation of millions of fiber optic cables, made the idea of **Fiber To The Home (FTTH)** networks real. However, the existing optical fibers still present capacity limits to deal with the growing amount of transmitted data, so the current optical communication systems need a new direction of improvement.

The capacity of optical fiber network systems can be calculated using the **Shannon limit** [1]. It describes the maximum rate at which data can be sent in one channel with a given bandwidth and noise characteristics. In optical fibers, there exists a **barrier of capacity** which is related to the limited amount of power that can be transmitted in a fiber without causing nonlinear effects [2]. According to this, a capacity higher than 100Tb/s cannot be achieved in a standard Single-Mode Fiber (SMF) [3], which is insufficient to meet the future demand. As nowadays there is a **growing need for information** (e.g., Internet of Things, cloud storage, 5G) **with the best possible quality** (e.g., expansion of HD TV, video in 8K resolution), new technology is needed to manage the actual requirements in IP Traffic [4].

The most obvious way to increase the capacity of optical fiber systems is to deploy cables with higher fiber counts. However, a less evident problem is starting to emerge, especially in highly dense urban areas: **the existing infrastructure is not capable of accommodating a larger number of optical fiber cables**. This is due to two main reasons. On the one hand, the cost of cable ducts as well as cable installation should be minimized, and, on the other hand, optical fiber telecom systems need to follow the trend towards miniaturization and integration in nowadays technology.

SPACE DIVISION MULTIPLEXING – OVERVIEW

One of the new promising approaches for rethinking telecommunication systems is called **Space-Division Multiplexing (SDM)**. SDM makes use of multiple cores and/or modes (in a single fiber) as separate 'spatial' channels. This technology is recognized as the most efficient way to meet the challenge of increasing the capacity of telecommunication networks without increasing the amount of cable (Fig. 1), while simultaneously reducing installation costs.

SDM can be realized in two ways. Firstly, **Mode Division Multiplexing (MDM)**, which uses modes in a Few- or Multi-Mode Fiber (FMF or MMF respectively) as separate channels. This strategy has brought up several remarkable capacity records (e.g., 2.05 Pb/s [5] or 2.15 Pb/s [6]). However, these networks require massive multiple-input and multiple-output (MIMO) techniques and advanced Digital Signal Processing (DSP), which requires huge computing power and offline processing. Secondly, by using the SDM technique with single-mode cores (**multicore single-mode fibers**), one can omit the costly DSP and profit from all the **advantages of the existing networks**. Although MDM may appear to be the future of telecommunication, the industry has its sights set on technologies, by which **better transmission capacity** can be achieved **in a cost-effective manner**.

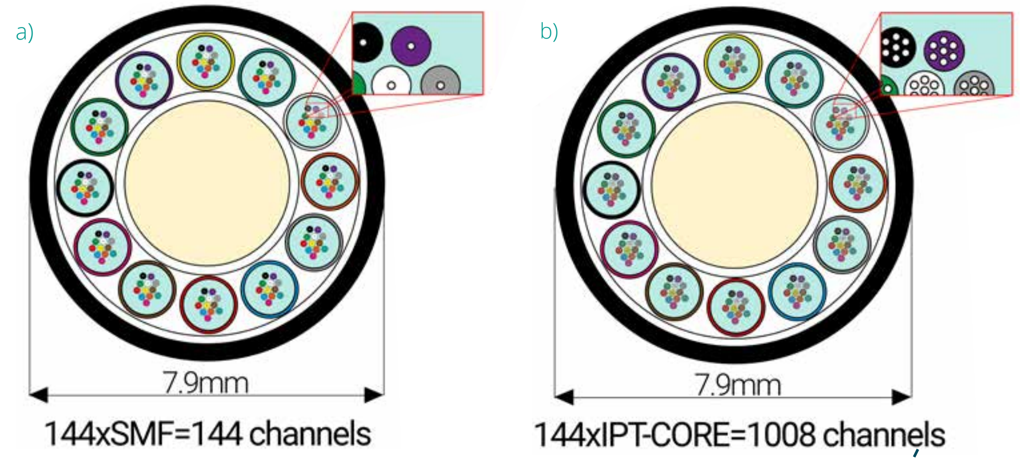

Fig. 1. a) Fiber optic cable with SMFs; b) Fiber optic cable with InPhoTech's MCF.

DESIGN FUTURE WITH PHOTONICS

WHY USE INPHOTECH'S MULTICORE FIBERS?

Multicore fibers (MCF) by InPhoTech constitute an **innovative solution** dedicated to SDM. These **standard diameter fibers** contain 7 separated cores (with 19-cores available in a fiber with a larger diameter). In our approach, each single-mode core of our MCF is in compliance with the ITU-T G.652 recommendation so that well-developed multiplexing methods like **WDM can be used effectively**.

In order to easily and quickly deploy multicore fibers for industrial application, InPhoTech has created a fiber design which can be implemented in the existing networks (Fig. 2). InPhoTech's MCF based system consists of a 7-core or a 19-core passive optical fiber together with fan-in/fan-out components on both ends of the fiber. The fan-in/fan-out component allows to send and receive information to/from each core independently, thus effectively providing **the functionality of 7 or 19 fibers within a single fiber**. Furthermore, we can also provide 1x7 all fiber power splitters and erbium doped active multicore fibers (active MCF) for signal amplification. By that, InPhoTech's solution can be used in **long-haul, metro or access networks** without replacing the existing transmitting-receiving devices.

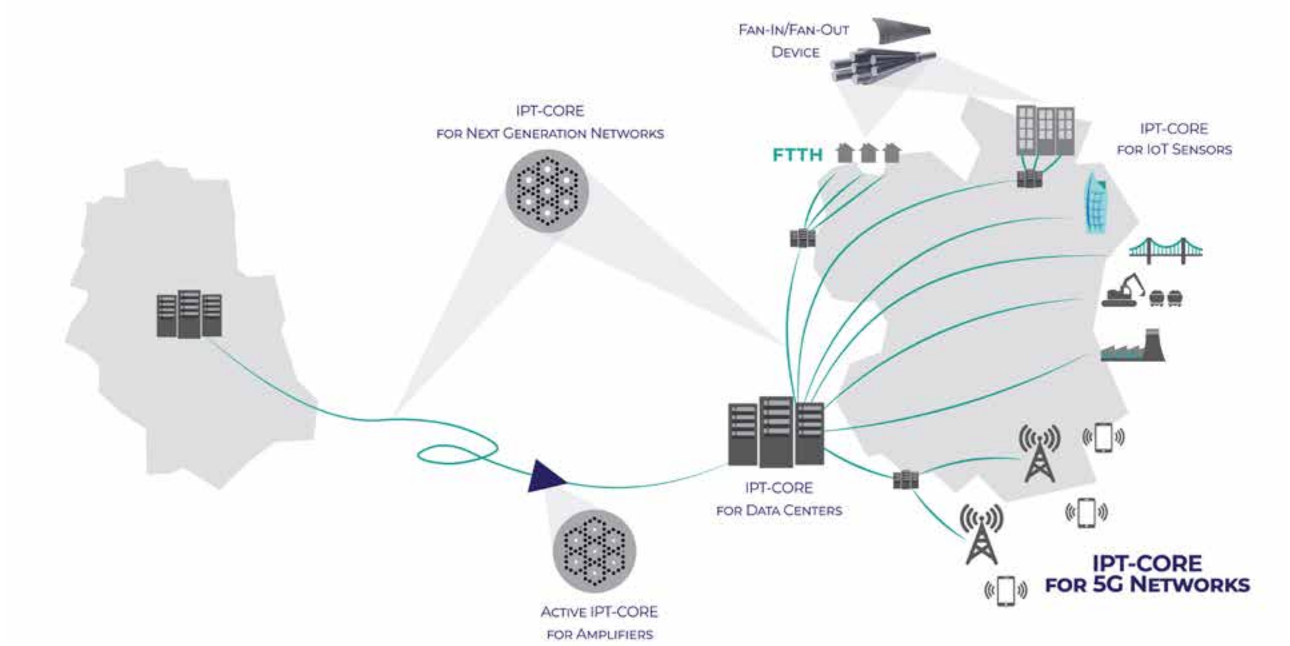

Fig. 2. Illustration of the use of InPhoTech's Multicore Fiber technology.

The employment of MCF is a crucial step in the pursuit of modern technology. **InPhoTech's solution has no competition in the market**, as it is the only ready-to-apply technology, which does not impose any changes to active components of the legacy systems as required by telecom carriers and service providers for their gradual network evolution. Moreover, when the market is able to adopt MDM solutions, InPhoTech will be prepared as we are also developing MDM multicore fibers. This type of future fiber telecommunication system will provide an exponential growth of the number of channels in a single fiber. This **migration scenario** is presented in Fig. 3.

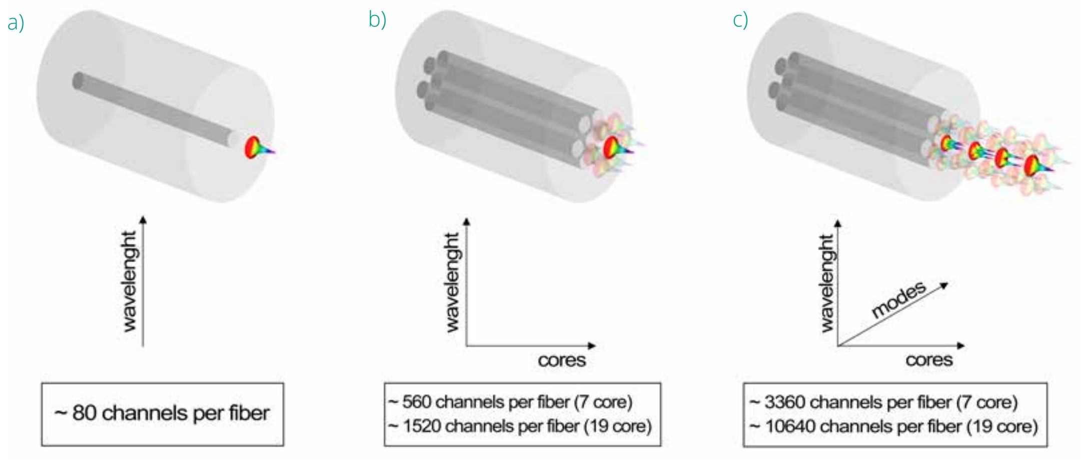

Fig. 3. From today to the future with InPhoTech's MCF. a) SMF + WDM; b) MCF + WDM; c) MCF + WDM + MDM

FIBER DESIGN - OVERVIEW

InPhoTech's MCF is composed of basic cells (Fig. 4a). In each cell, a GeO_2 doped core is surrounded by air-holes. The refractive index contrast between the core and cladding is the same as in an SMF, which keeps the **mode field diameter and dispersion within the requirements of ITU-T G.652**. The basic cells are combined in a hexagonal lattice forming the 7-core (Fig. 4b) or 19-core (Fig. 4c) fiber.

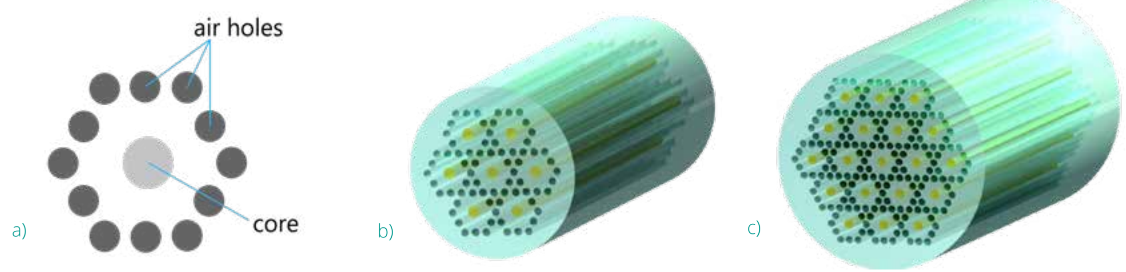

Fig. 4. a) MCF's basic cell; b) 7-core fiber design; c) 19-core fiber design.

ROLE OF AIR-HOLES

The role of the air-holes in the basic cell is twofold. Their main function is to **isolate cores from each other**, thereby eliminating crosstalk and increasing core density. The second role is to **reduce macrobend loss**, and thus, make the fiber bend-insensitive [7] – InPhoTech's MCF goes beyond the requirement set by the most demanding ITU-T G.657.B3 recommendation.

The fiber's structure also contains **three markers** (depicted in Fig. 5). They facilitate the **clear identification** of the cores and provide the possibility to orientate the fiber automatically.

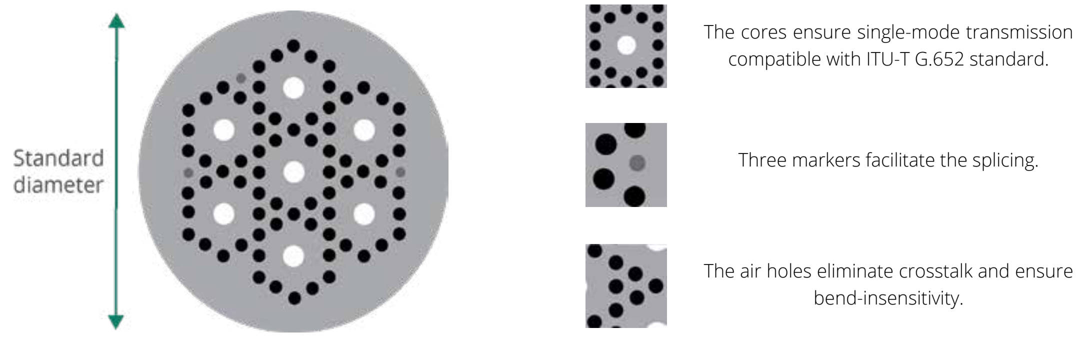

Fig. 5. InPhoTech's MCF structure with its characteristic elements.

THE IMPACT OF AIR HOLES

The main idea behind InPhoTech's MCF design was to fulfill all the requirements of ITU-T G.652 recommendation. For this reason, the guided fundamental mode should 'see' the same refractive index distribution as in a standard single-mode fiber.

According to MCF design, it is worth noting that the vast majority of the light in each core is guided in **exactly the same way as in standard telecom fibers** (see Fig. 6). This means that the essential properties of MCF's basic cells, such as the dispersion characteristic and the effective mode area, are non-distinguishable from those of a standard telecom fiber.

On the other hand, the evanescent wave of the fundamental mode is greatly reduced by the presence of the air holes, which allows **the crosstalk phenomenon** to be avoided (described in detail in [8]) and the macrobend loss to be reduced.

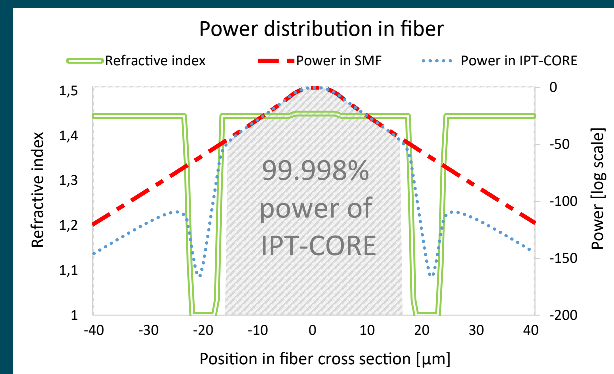

Fig. 6. Refractive index distribution in a MCF (green) and power distributions of the fundamental mode of a MCF (blue) and of a single-mode (red).

DESIGN FUTURE WITH PHOTONICS

FIBER PROPERTIES

The silica cladding of InPhoTech's Multicore fibers has a hexagonal shape (Fig. 7a-b), which is coated with a standard circular coating (Fig. 7c). Thus, MCF **can be operated like standard SMF** (with standard stripping and cleaving tools). Moreover, these fibers **can be spliced with standard splicers**, as the collapse of the air-holes in the splice region does not result in induced XT.

Practically **no crosstalk can be observed in** MCF**,** measuring a XT_{max} of < -40dB at 1550 nm. This result allows the cores to be treated as totally separate channels. The design of the 7 and 19 core fibers enables the transmission loss to be brought down to the level of traditional optical fibers. The zero dispersion wavelength of the IPT-CORE fiber is in the range from **1300-1324 nm**, while the dispersion slope remains below **0.092 ps·nm^{-2}·km^{-1}** and the dispersion at 1550 nm below **18.5 ps·nm^{-1}·km^{-1}**.

MCFs are **bend-insensitive**. We went **beyond the ITU-T G.657.B3 recommendation,** achieving a loss below 0.1 dB for 10 turns on a 5 mm radius mandrel. Furthermore, the test of total bend -insensitivity confirms that **no bend induced XT** appears.

a) b) c)

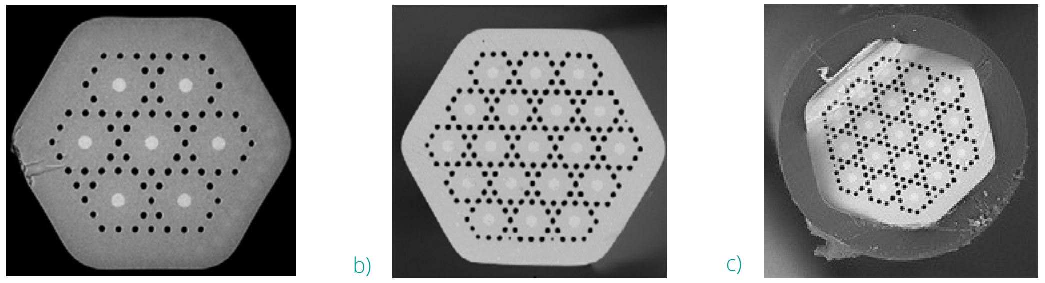

Fig. 7. Microscope images of the cross-section of a) 7-core fiber b) 19-core fiber c) 19-core fiber with coating.

CROSSTALK PHENOMENON

Inter core crosstalk (XT), a property that is absent in single-core fibers, plays a major role in the performance of multicore fibers [8]. XT causes some part of the power in an excited core to be transferred to another core. Thus, we can define a maximum crosstalk (XT_{max}) for a given structure as the relation between the maximum power level in the eavesdropped core (indexed with n) and maximum power level in the initially excited core (indexed with m):

$$XT_{max} = 10log\frac{\max(P_n(z))}{\max(P_m(z))}$$

According to this formula, XT ranges **from -∞ dB to 0 dB**, which respectively stands for no power being observed in the core that was not initially excited and all the power being transferred from the excited core to another.

The crucial task in fiber design is to **reduce the unwanted presence of neighboring signals** in the signal that is received. Basically, this can be done in three ways:

1. Increasing core to core distance.
2. Introducing refractive index depression (trench-assisted or hole-assisted cores).
3. Differentiating core sizes or their doping.

InPhoTech's innovative technology is based on the use of a hole-assisted structure to elliminate the XT between the cores.

CONCLUSIONS

In order to meet the constantly increasing demand for capacity in optical systems, we present **7 core and 19 core fibers** designed by InPhoTech as the **key enablers** of the new generation transmission systems based on SDM.

Multicore fibers by InPhoTech assure **negligible core-to-core crosstalk** and enable the **fulfilment of the ITU-T G.652** recommendation for each core. The compatibility with standard SMF systems is maintained in terms of modal properties (single mode propagation, mode field diameter) and dispersion characteristics (zero dispersion wavelength within the range 1300-1324 nm, dispersion slope below 0.092 ps·nm^{-2}·km^{-1} and dispersion at 1550 nm below 18.5 ps·nm^{-1}·km^{-1}). Furthermore, each core is **bend-insensitive** (less than 0.1 dB at 10 turns on a mandrel of 5 mm radius) so that the requirements of the most demanding recommendation of **ITU-T G.567.B3 are fulfilled**. InPhoTech's MCF can be used **together with other multiplexing methods like WDM** to allow users take full advantage of the potential of SDM.

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BREAK THE LIMITS WITH PHOTONICS

InPhoTech is a R&D company focusing on optical fiber technologies. Our mission is to design the future with photonics. We open the fascinating world of photonics to our clients by offering ultramodern tools to solve everyday challenges. We deliver innovation to all industries, from telecom, to medicine, to the space industry.

CREATE MODERN AND COMPETITIVE INDUSTRY WITH OPTICAL FIBERS