It would be highly desirable if we could optimize the design of the trench-assisted MCF to have the large effective area, low inter-core crosstalk, and acceptable cable cutoff wavelength simultaneously. However, it appears to be a difficult task. In order to suppress the inter-core crosstalk in the trench-assisted MCF, it was necessary to increase the index difference of the trench. However, this increased index difference of the trench could also increase the effective index difference between the core and cladding and, as a result, reduce the effective area. We could of course suppress the inter-core crosstalk without this problem by increasing the width of the trench or the spacing between the core and trench layer. However, in this case, the cable cutoff wavelengths of the neighboring cores could be increased. Thus, there was a trade-off between the inter-core crosstalk and the cable cutoff wavelength for the design of the MCF having large effective area. In other words, the spatial efficiency improvement achievable by designing the MCF to have low inter-core crosstalk (i.e., by increasing the width of the trench) could be negated by the increased core pitch required to support the shortest wavelength used in the system. Thus, we concluded that the optimum effective area for maximizing the SSE-distance product was ~110 μm^2 for the trench-assisted MCF.

5. Summary

We evaluated the effects of using multi-level modulation formats on the transmission capacity of the MCF having trench-assisted index profile and hexagonal layout. To maximize this capacity, it would be vital to utilize the multi-level modulation formats. However, since the higher-level format was more sensitive to the inter-core crosstalk, it was indispensable to utilize the larger core pitch in the MCF for the transmission of the signals modulated in such a format. This would inevitably deteriorate the spatial efficiency. As a result, the ultimate fiber capacity per unit area achievable by using the high-level format in the MCF transmission system was smaller than expected. For example, in the 500-km long MCF link, the SSE improvement by using 16QAM signals instead of QPSK signals was estimated to be only ~75% (instead of 100% achievable in the conventional SMF link). This tendency became more serious as the transmission distance was increased. For example, this SSE improvement was reduced to ~53% when the distance was increased to 1400 km. We also evaluated the effects of increasing the effective area on the transmission capacity of the trench-assisted MCF. When we increased the effective area of each core in such an MCF, not only the inter-core crosstalk was increased but also the cable cutoff wavelength was shifted to the longer wavelength. To overcome these problems, it was necessary to increase the core pitch of MCF, which, in turn, deteriorated the spatial efficiency. As a result, the use of large effective area in the MCF was detrimental for maximizing its capacity, although it could help increasing the transmission distance. Thus, it would be necessary to optimize the effective area of each core in the MCF by considering both the SSE and transmission distance. For this purpose, we evaluated the SSE-distance products achievable by using various types of the modulation formats in the transmission links implemented by using MCFs with various effective areas. The results showed that we could achieve the largest SSE-distance product by using MCF B, indicating that there might be no need to increase the effective area of the trench-assisted MCF to be larger than 110 μm^2. However, the impact of the size of the effective area on the SSE-distance product was not very significant. The results also showed that the largest SSE-distance product could be achieved by using the QPSK format than the 16QAM or 64QAM format in the MCF link consisted of trench-assisted MCFs.

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