Erbium-Doped Fiber Design for Improved Splicing Performance

Torben Veng and Bera Pálsdóttir
OFS Fitel Denmark I/S

Abstract

Fusion splicing is a well-known technique to connect a fiber pair and fusion splicers have been commercially available for this process for a long time. An important feature of a fusion splice is the coupling loss that is influenced by - among other things - the mutual spotsizes of the two fibers involved. Hence, similar fibers such as standard single mode fibers can be spliced to nearly zero loss whereas dissimilar fiber pairs may give higher loss. The latter category covers the splice combinations of erbium doped fibers that are often spliced to other fiber types such as the standard single mode fiber.
We have investigated how splice loss of dissimilar fibers is influenced by fiber design with emphasis on this combination. Finally we propose a fiber design suitable for optimizing splicing capabilities of erbium doped fibers. With this design it is possible to keep fiber cutoff below 980 nm, which is of importance for practical applications, a requirement that usually conflicts with the demand for good splicing properties. An actual design, has been manufactured and splicing properties for this and the conventional design are compared.

Introduction

Splicing capability of erbium doped fibers (EDFs) to dissimilar fibers such as standard single mode fibers (SSMFs) is an important performance parameter. This splice combination, used in optical amplifiers is especially difficult, since low loss is preferred for a wide wavelength range. For production environment, reproducibility is of great importance and attention has already been given to this, however mainly with respect to homogeneity of fiber gain spectra[1]. Low splice loss in the C-band and/or L-band is important to achieve low noise figure for the amplifier. In some configurations the EDF is pumped via the SSMF, at a wavelength below 1550 nm, and minimal splice loss at the pump wavelength gives better power conversion efficiency for the amplifier. Also, splice losses are often measured outside the absorption band, for example @ 1310 nm.
Since the two types of fibers usually have substantially different mode field diameters (MFDs), unacceptable high loss is obtained if not the MFDs are altered at the splice joint so that these match. It is well known that this can be done by diffusing the EDF refractive index profile during splicing[2]. Therefore, acceptable loss can be obtained at a certain wavelength by optimizing the splice parameters. However, this does not necessarily mean that losses are low enough at other wavelengths, since this will require that the altered fibers have same evolvement in MFD with wavelength. This will however be the case if the two fiber profiles become similar at the splice joint. Ideally, if we neglect diffusion in the SSMF, the EDF should therefore be designed in such a way that it diffuses to become

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nearly similar to the SSMF. In practice, if looking at step like EDF designs, we have experienced that this requirement conflicts with another constraint, namely that the EDF cutoff should be below the 980 nm, a pump wavelength commonly used in amplifiers. This can be understood by following intuitive arguments. The cutoff for the step profile is approximately related to the core index Δn and radius r as follows[3]:

$$\text{Cutoff} \propto r * (\Delta n)^{1/2} \quad (1)$$

Then, if we assume that Δn and dopants concentration are proportional, the SSMF is unaltered after splicing, and that the diffused EDF is fairly approximated by a step profile, we get following requirement between EDF and SSMF cutoff:

$$\text{Cutoff(EDF)} \sim \text{Cutoff (SSMF)} \qquad (2)$$

- since the “volume” $\Delta n * r^2$ is preserved with the mentioned assumptions and is a quantity we want to be the same for the fibers at the joint, according to the discussion above. Typically, the SSMF cutoff is 1250 nm, far above the requirement for the EDF.
All this is illustrated in Fig. 1, which shows the profiles of two types of EDFs - one with cutoff = 925 nm and the other with cutoff = 1300 nm - after diffusion at the splice joint. The fibers have been spliced, cleaved at the joint and then profiled with a refractive index profiler. As one can see in Fig. 1a) the fiber with cutoff below 980 nm never matches the profile of the SSMF, whereas the EDF in Fig. 1b) becomes nearly identical to the SSMF. All fibers discussed in this work have cores consisting of either Al/La/Er or Al/La, hence the influence of Er on splice performance is neglected.
Another argument for increasing the cutoff or “volume” $\Delta n*r^2$ is that it requires more diffusion to expand the mode-field, and we have experienced in general that this lowers the taper loss, i.e. the loss that might arise by the change in mode-field along the direction of propagation. Fig. 2 is a map of the splice loss between the two EDFs and an SSMF at 1550 nm, and this map is a relatively simple way to get an overview of splice performance: Splice losses are monitored during splicing for different splicing currents. The legends on the figures indicate the different fusion currents used. As seen in the figure, best loss is obtained for the fiber having highest cutoff. The aforementioned issues with wavelength dependence will be discussed in next section.

New EDF design

Based on these results, it seems attractive to come up with an EDF design where both the cutoff requirement and a larger core volume can be obtained. An example of such a design is shown in Fig. 3.The volume is increased by a region around the core with a raised index. The region may of course have numerous shapes. The region raises cutoff and therefore an outer trench is added, since this lowers the cutoff. Another feature, just as important, is that the shape of the region surrounding the core can be optimized with respect to taper loss, i.e. so that MFD is expanded sufficiently gradual along the fiber axis.

An advantage of this design is that no significant changes of the core are required to improve splice performance for a given step index design. This is important, as MFD and core composition have influence on amplifier design and gain spectra. To demonstrate the principle, a fiber was made, having nearly the same core shape and composition as for the one used in the splice test in Fig. 2a). The volume increasing region was made by Ge doping and the trench was F doped. The cutoff for this fiber was 951 nm, nearly the same as for the fiber in Fig. 1a) Corresponding splice curves for the new fiber is shown in Fig. 4, and is seen that losses are significantly reduced from the previous 0.20 dB to less than 0.10 dB.

As mentioned in previous section, a critical issue is the wavelength dependence of the splice loss. Therefore, a comparison between an EDF similar to the one used in Fig. 2a) and the new design was made with respect to losses at three wavelengths, 980, 1310, and 1550 nm. This was done by using various sets of splice time and power and then measuring the loss at all the wavelengths. Additionally, the splicer used for the above discussed data was substituted with another type, to ensure that low losses were not related to the actual splice unit used. The results are shown in Fig. 5 for 980 and 1550 nm. Though the SSMF is not single moded at 980 nm, measured losses were consistent, likely because the high order modes were stripped in the SSMF with actual setup. Power levels are indicated by the legends, and each dot corresponds to a certain fusion time. Best wavelength independent loss was about 0.20 dB for the conventional design whereas losses went below 0.10 dB with the new design for optimal splice parameters. This was also the case when including data @ 1310 nm. The taper loss, that is included in the loss curves in Fig. 5, is evidently minimal for the new fiber.

Finally, we splice tested the new design to a low-cutoff coupler fiber (980-20™) – which is also a splice of importance in amplifiers - and losses below 0.10 dB at all three wavelengths were obtained.

Conclusion

To summarize, we have proposed a new design for erbium doped fibers, suitable for optimizing splice performance, but at the same time meeting other requirements such as a sufficiently low cutoff. An actual fiber was made and a reduction of splice loss to a standard single mode fiber of about 0.10 dB @ 1550 nm was obtained when compared to a conventional erbium doped fiber. The proposed design may also be useful for optimizing other kinds of fibers with respect to splicing.

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References

[1] B. Palsdottir, S. Primdahl, P. Gaarde, G. Puc, and B. Wang, “Consistency in Gain Spectra of Erbium Doped Fibers,” Proc. Optical Fiber Communication Conf., Atlanta, Georgia, USA, paper ThZ1, pp. 599-600, 2003.

[2] H. Y. Tam, “Simple fusion splicing technique for reducing splicing loss between standard singlemode fibres and erbium-doped fibre,” Electron. Lett., Vol. 27, No. 17, pp. 1597-1599, 1991.

[3] D. Marcuse, “Loss analysis of Single-Mode Fiber Splices,” B. S. T. J., Vol. 56, No. 5, pp. 703-718, 1977.

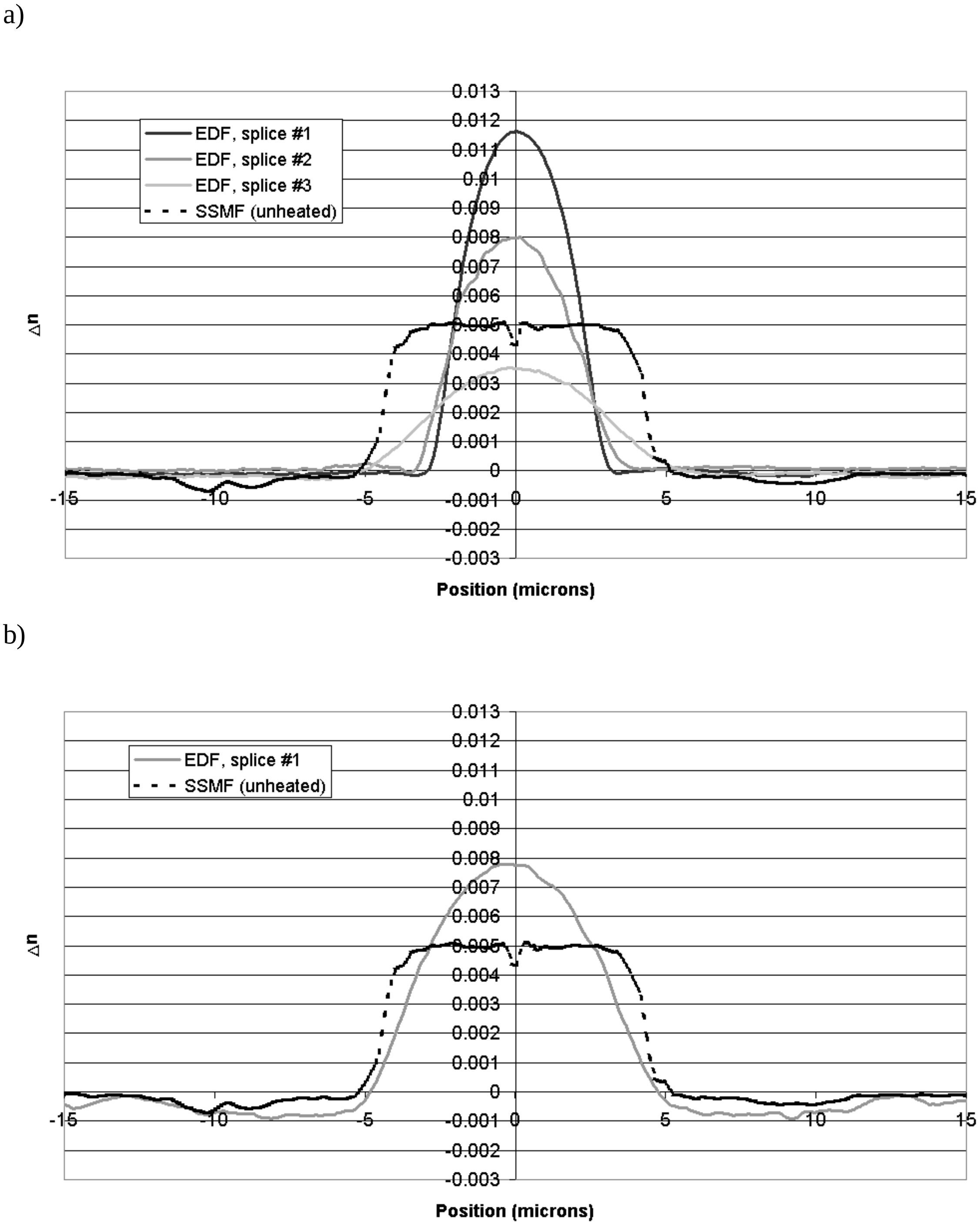
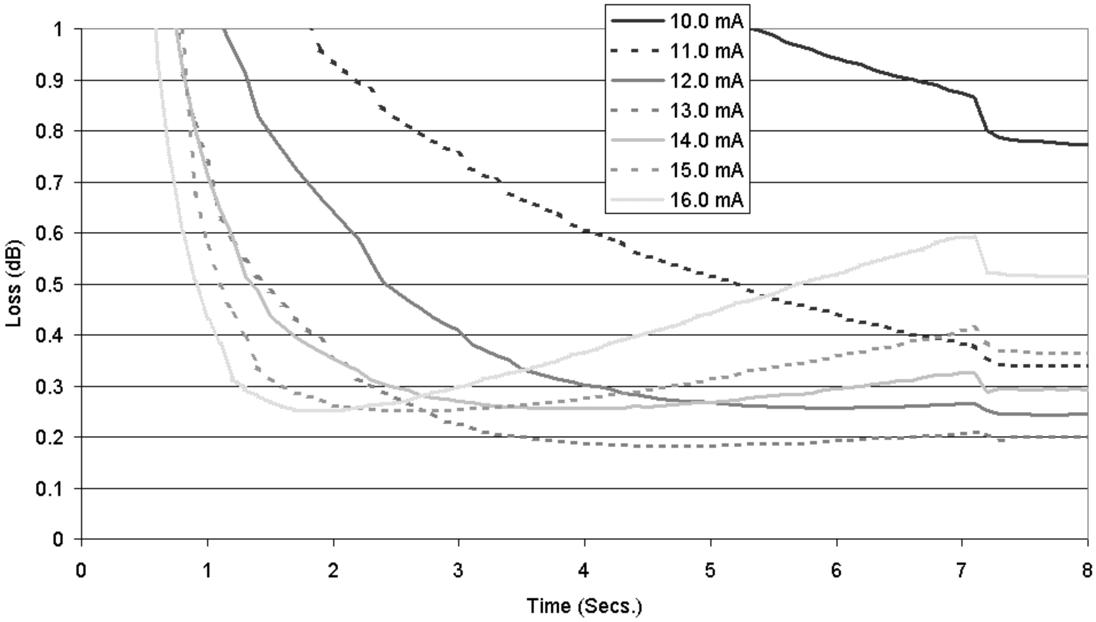


Fig. 1. Comparison between EDF and SSMF at splice joint. a) EDF for different amounts of heating, EDF cutoff = 925 nm and b) an EDF with cutoff =1300 nm.

a)



b)

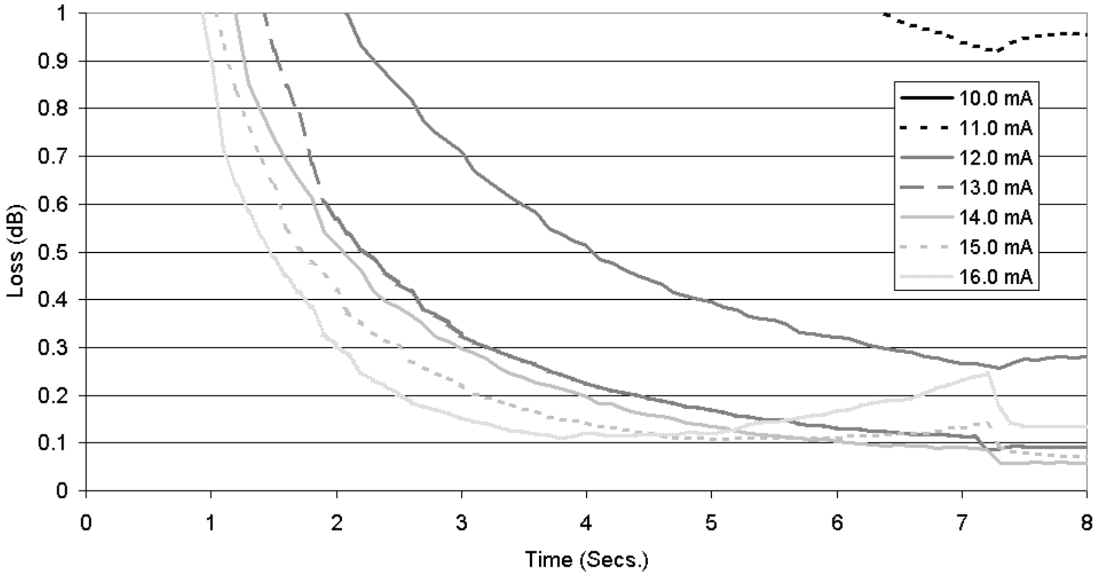


Fig. 2. Splice loss curves between EDF and SSMF at 1550 nm for a) an EDF with cutoff = 925 nm and b) an EDF with cutoff = 1300 nm.

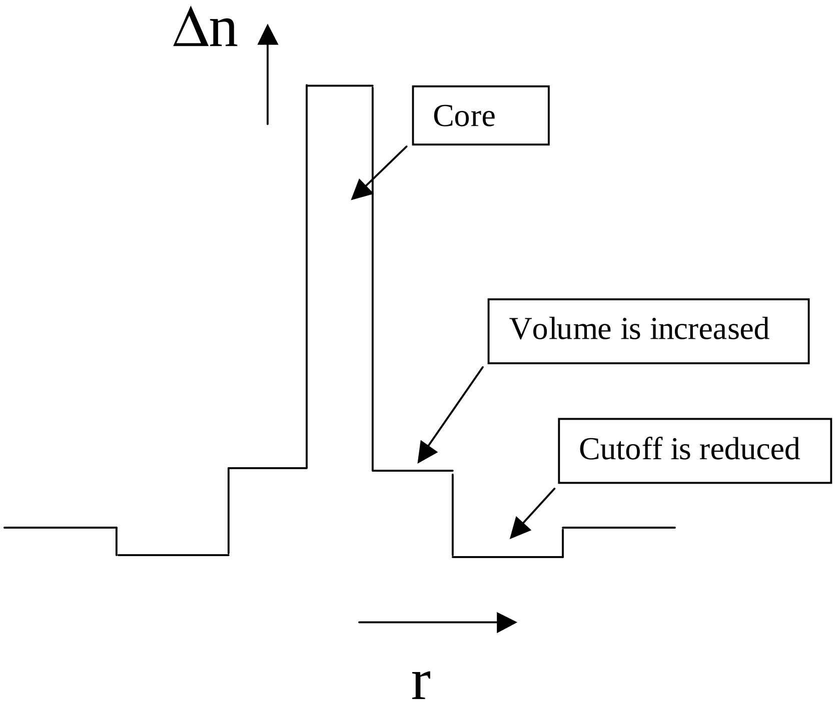


Fig. 3. Example of refractive index profile of EDF design for improved splice performance.

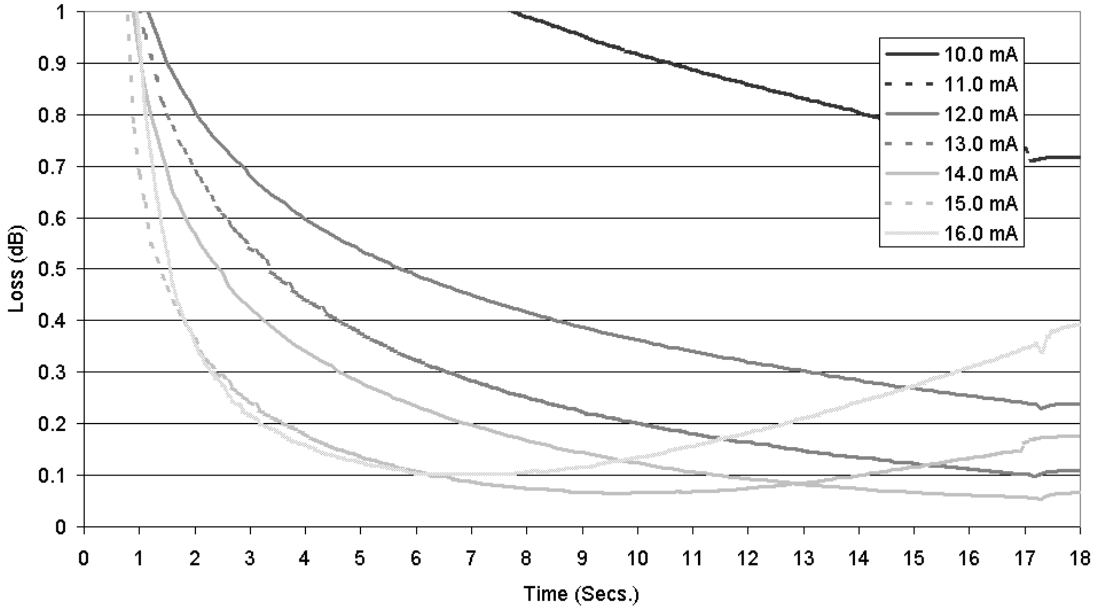
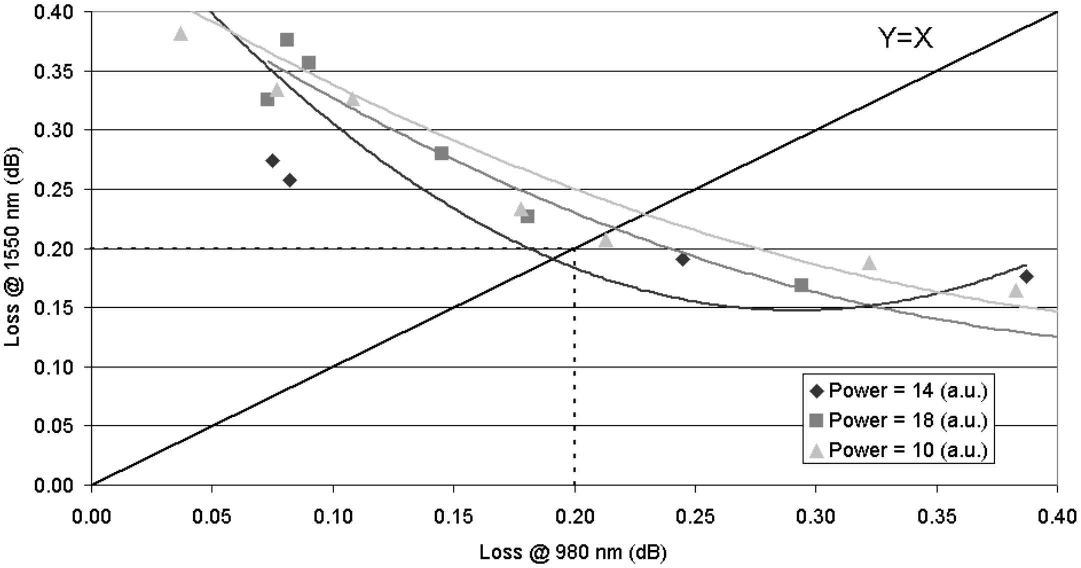


Fig. 4. Splice loss curves @ 1550 nm between SSMF and new EDF design.

a)



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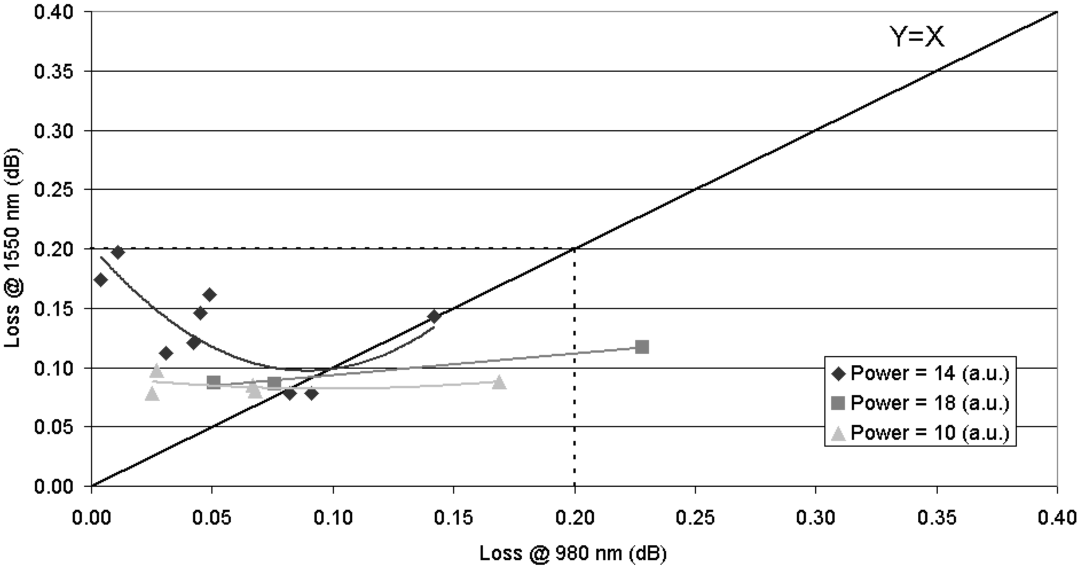

Fig. 5. Dependence between splice loss @ 1550 nm and @ 980 nm for a) an EDF with cutoff = 925 nm and b) new EDF design.