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ANALYSIS OF THE RELATION BETWEEN THE DIAMETER OF THE CORE OF SILICIA OPTIC FIBRES AND THE BENDING LOSSES

Macrobending loss model

The macrobending loss γ is a radiative loss when the fiber bend radius is large compared to the fiber diameter. It is defined as usual by $P(z) = P(0)\exp(-\gamma z)$ where $P(0)$ is the input power and $P(z)$ is the output power at distance z respectively.

Currently we can implements two different macrobending loss models:

1. The first model uses the closed-form integral formula, published by J. Sakai and T. Kimura [1]. It is appropriate for calculating the macrobending loss of any LP mode, both fundamental and higher-order, in arbitrary-index profile optical fibers. Using this formula the macrobending power loss coefficient is expressed as a function of the bending radius R_b in the form:

$$\gamma = \frac{\sqrt{\pi}\left(\frac{P_{clad}}{P}\right)}{2sr_c\left[K_{v-1}(W)K_{v+1}(W)\right]}\frac{\exp\left(\frac{-4\Delta W^3}{3r_c\Delta V^2}R_b\right)}{W\sqrt{\frac{WR_b}{r_c}+\frac{V^2}{2\Delta W}}}. \tag{1}$$

The arameters appearing above are given by:

$$V = k_0 r_c\sqrt{N_{\max}^2 - N_{\min}^2}, \tag{2}$$

(the normalized dimensionless frequency)

$$W = r_c\sqrt{\beta^2 - \left(k_0 N_{\min}\right)^2}, \tag{3}$$

$$\Delta = \frac{N_{\max}^2 - N_{\min}^2}{2N_{\max}^2}, \tag{4}$$

where r_c denotes the fiber core radius, $N_{\max}$ and $N_{\min}$ are the maximum and minimum values of the refractive index, β is the propagation constant of the mode, k_0 is the prop. constant in vacuum, n is the azimuthal mode number, $s = 2$ if $v = 0$ or $s = 1$ for $v \neq 0$ and K_v is the modified Bessel function of the second kind of order v.

2. Using the second macrobending loss model the coefficient γ can be expressed published by Snyder and Love, 1992 [2, 3] as:

$$\gamma = \sqrt{\frac{\pi V^8}{16 r_c R_b W^3}}\exp\left(\frac{-4}{3}\frac{R_b}{r_c}\frac{\Delta W^3}{V^2}\right)\frac{\left[\int_0^\infty (1-f)F_0 R\,dR\right]^2}{\int_0^\infty F_0^2 R\,dR}, \tag{5}$$

where F_0 is the radial field of the fundamental mode,

$$f = \frac{N(R)^2 - N_{\min}^2}{N_{\max}^2 - N_{\min}^2}, \qquad (6)$$

and $N(R)$ is the refractive index profile of the fiber. The other parameters are given above.

The two models give similar results for step-index fibers.

The loss coefficient γ can be converted to loss in decibels per kilometer units as follows:

$$\alpha_{\text{macro}} = \frac{10}{L}\log\left(\frac{P_{\text{in}}}{P_{\text{out}}}\right) = \frac{10}{L}\log\left[\exp(\gamma L)\right] = \frac{10}{\ln(10)}\gamma, \qquad (7)$$

where L is the length.

Microbending loss model

Microbending loss is a radiative loss in fiber resulting from mode coupling caused by random microbends, which are repetitive small-scale fluctuations in the radius of the curvature of the fiber axis.

An approximate expression for the attenuation coefficient is given by Petermann, 1976 [4]:

$$\alpha_{\text{micro}} = A(kn_1 d_n)^2 \left(kn_1 d_n^2\right)^{2p} \qquad (8)$$

where A is a constant, d_n is the near field diameter, n_1 is the core refractive index of fiber, k is the free space wavenumber, and p is the exponent in the power law.

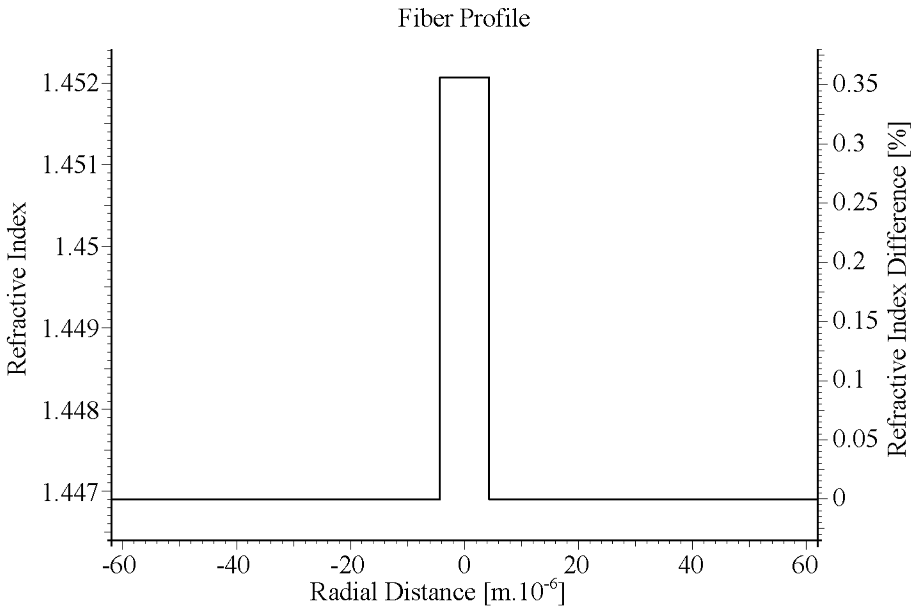

Fig. 1. Step index profile with core radius R =4.15 μm

For an standart step index SMF 8.3/125 μm (pure silica cover and core with 3.1 % germania-doped silica) where the radius of the core R = 4.15 μm (fig. 1) we can calculate the value for micro and macro bending loss (for wavelenght from 1.2 to 1.6 μm). The result is shown on fig. 2:

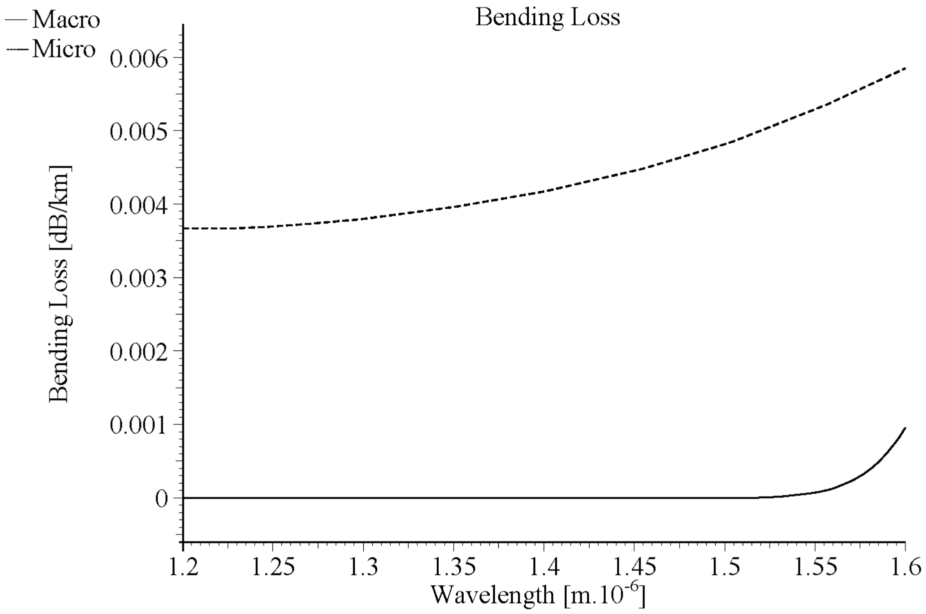

Fig. 2. Macro bending losses for fiber with core radius R =4.15 μm

If core radius of this fiber is R =15 μm (30/125 μm) we will calculate the value for micro and macro bending losses The result is shown on fig. 3.

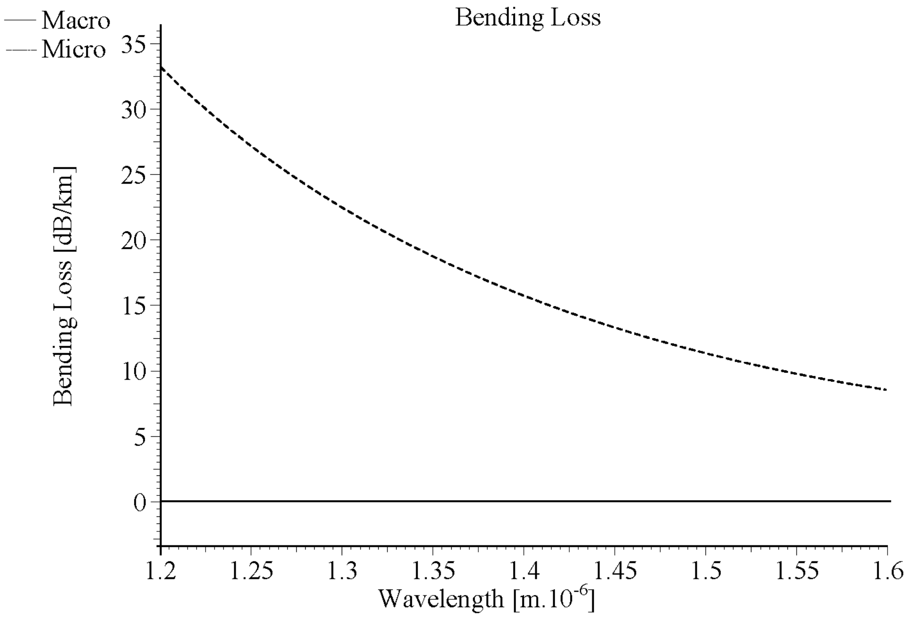

Fig. 3. Macro bending losses for fiber with core radius R =15 μm

For core radius of this fiber is R =3 μm (6/125 μm) we can calculate the next value for micro and macro bending losses. The result is shown on fig. 4.

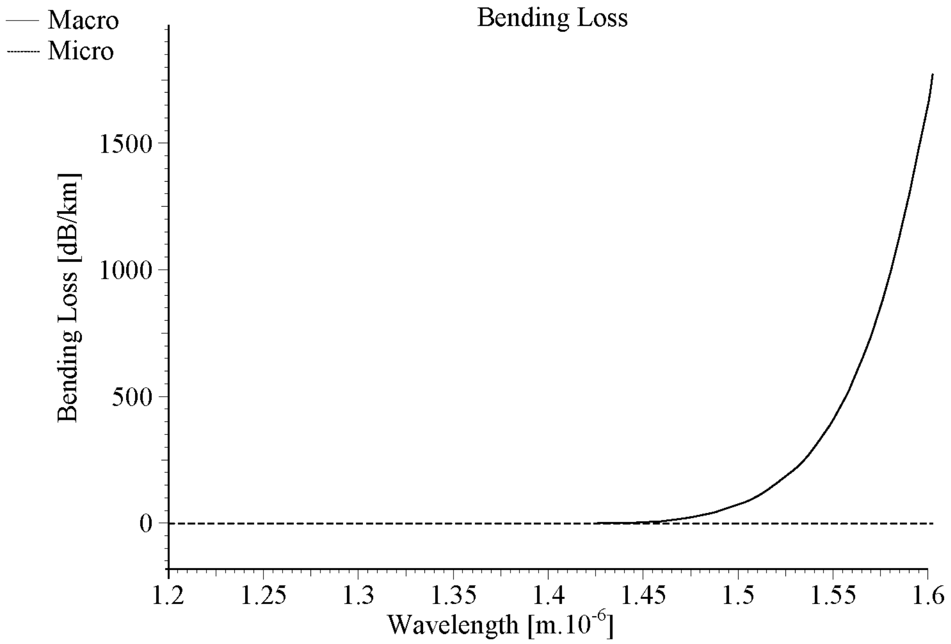

Fig. 4. Macro bending losses for fiber with core radius R =3 μm

If core radius of this fiber is R =2 μm (4/125 μm) we can calculate the value for micro and macro bending losses. The result is shown on fig. 5

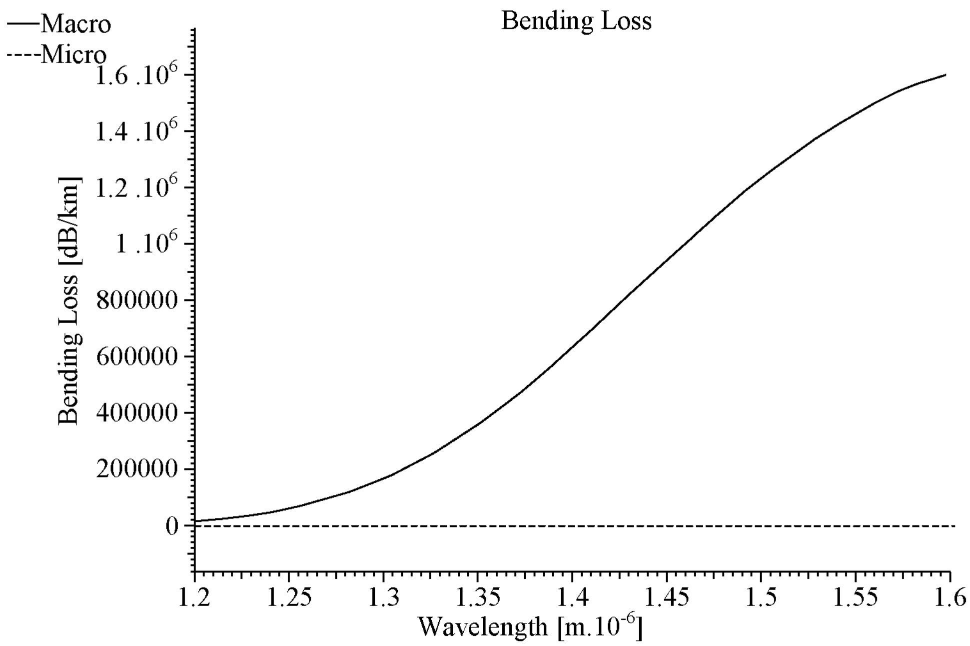

Fig. 5. Macro bending losses for fiber with core radius R =2 μm

For core radius of this fiber R =25 μm (50/125) we can calculate the value for micro and macro bending losses – showed in – fig. 6.

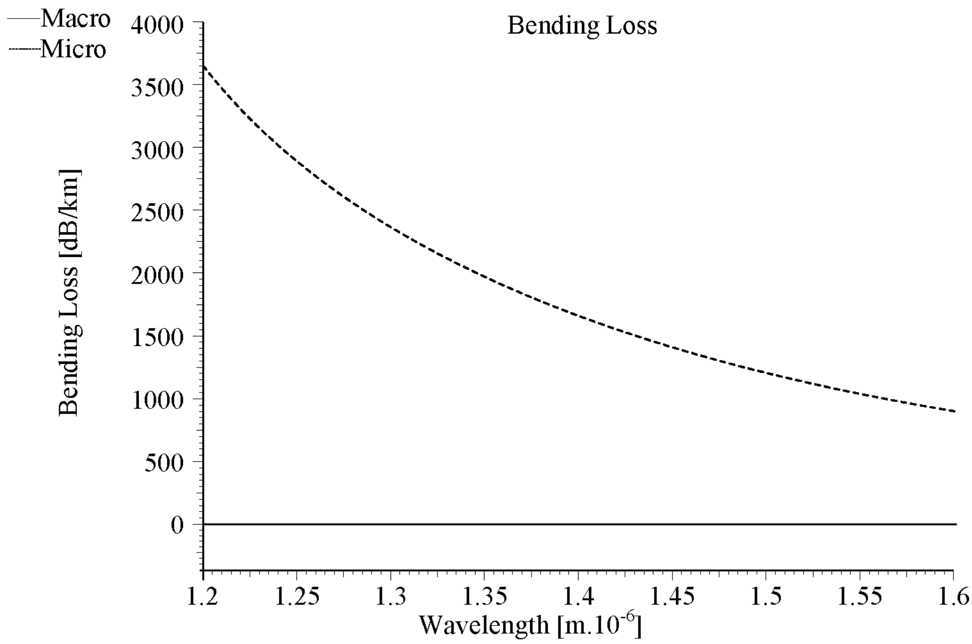

Fig. 6. Bending losses for fiber with core radius R =25 μm

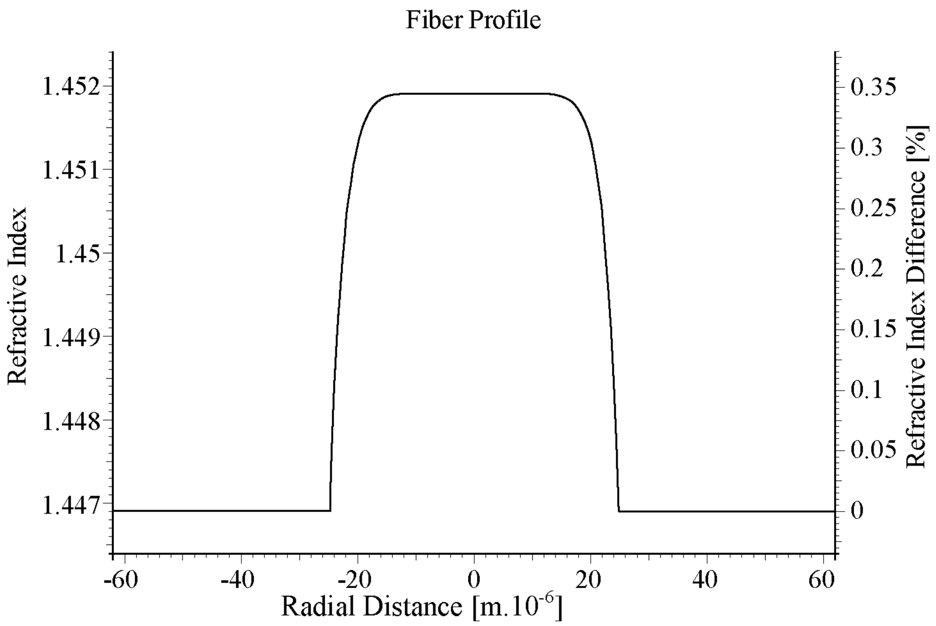

Fig. 7. Profile as a consequence from the diffusion of the material of the cover and the material of the core (50/125 μm)

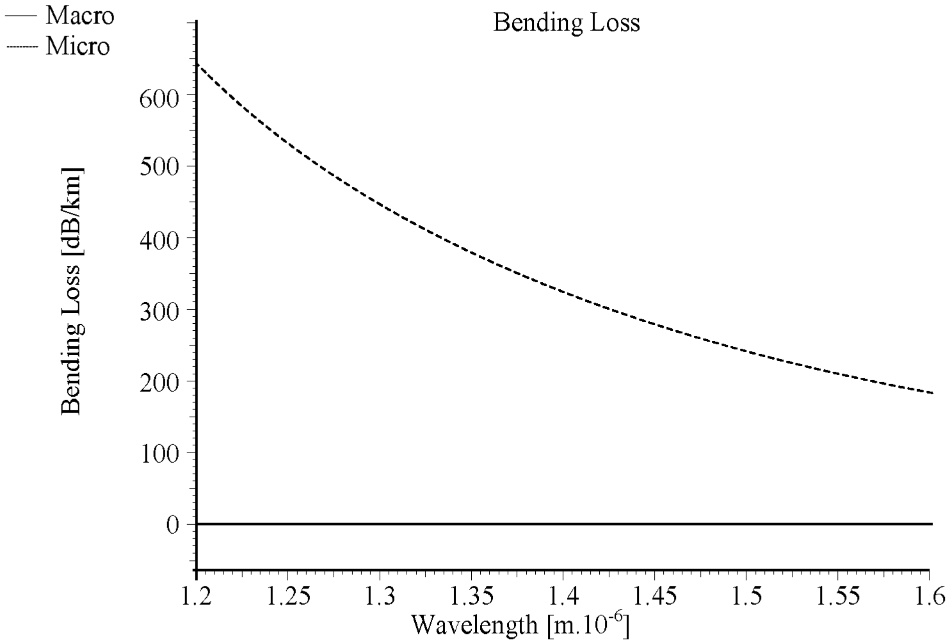

Fig. 8. Bending losses for fiber with profile corresponding to fig. 7

We can easily notice that with the increasing of the diameter of the core the value of the microbending loss is vastly increasing. If the radius of the core of this fiber is R =25 µm (50/125) we can notice this increasing in fig. 6. The value of the microbending losses according to the choosen refractive index in the core is so big that the fibre is practically useless.

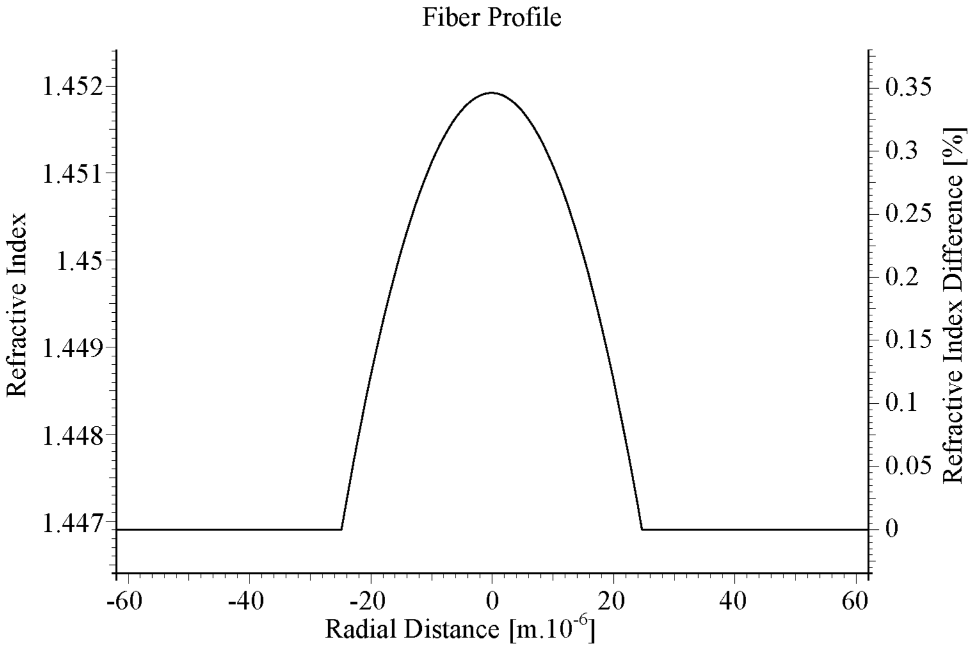

Fig. 9. Profile with exponent close to 2 (50/125 µm)

The problem could be solved if we use refractive index with gradient function in the core. Even the rounding of the profile of the index of refraction of the core (as a consequence from the diffusion of the material of the cover and the material of the core in the process of withdrawal of fiber with step index – fig.7) leads to vastly decreasing the value of microbending loss – fig.8.

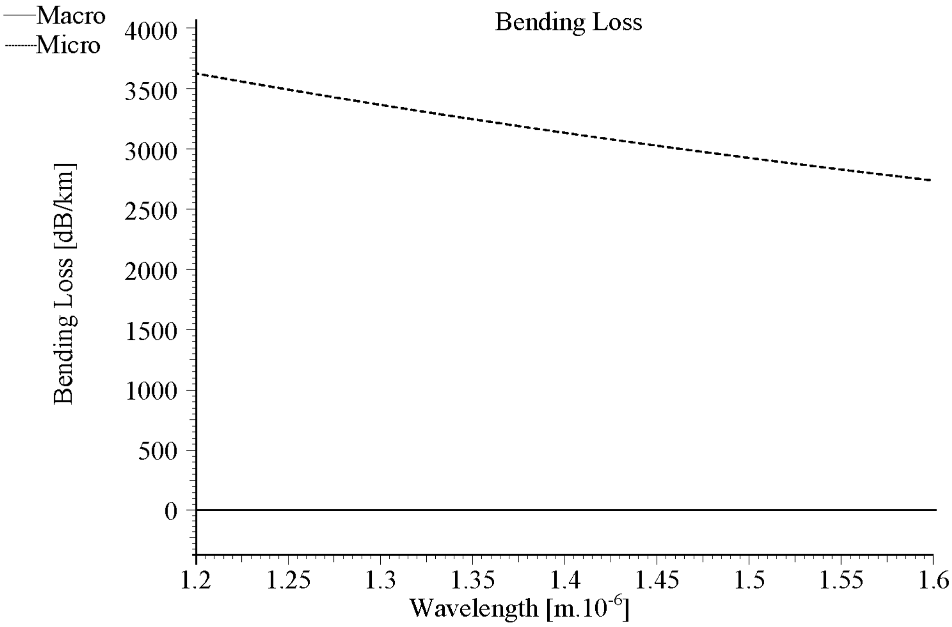

Fig. 10. Bending losses for fiber with profile with exponent close to 2

Pretty good results could turn out when using gradient profile with exponent close to 2 – fig. 9. The values of micro and macro bending losses are showed in fig. 10 .

For the calculations:

The near-field Mode Field Diameter (near-field MFD) is also known in the literature as the 'Petermann I' diameter. It is defined as the diameter at which the near field power falls to $1/e^2$ of its maximum value. It can be calculated by Artiglia [5]:

$$d_n = 2\sqrt{2\frac{\int_0^\infty E^2(r)r^3dr}{\int_0^\infty E^2(r)rdr}} \qquad (9)$$

where $E(r)$ is the optical mode field distribution.

The Mode Field Diameter (MFD) is an important parameter related to the optical field distribution in the fiber. It has been shown that MFD provides useful information about the cabling performances, such as possible joint, macrobending, and microbending losses. The effective area of the fibers has a direct relation to the nonlinear distortions in long fiber links.

According to what came out from the graphical dependence could be done the next conclusions for silicia optic fibers with step index:

1. The losses from the macrobendings vastly increase when the radius of the core of the single mode optical fibre with step profile of the coefficient of refraction under 3.5 μm.
2. The increasing is notably markedly in the big lenghts of the waves (over 1.5 μm or close over the third optical window).
3. The level of the losses from microbending goes down to reasonable level for the producing of single mode fibres good for real exploitation in the range of 1200–1600 nm in values of the radius of the core under 7 μм.
4. When $R < 5$ μм. the losses from the microbendings could be practically neglected.
5. The most advatageous, according to the fading from microbendings, are optical fibres with radius under 5 μм.
6. The most advantageous, according to the minimum losses together from the micro and macro bendings, appear to be the sizes of the radiuses of the cores of the fibers in the level between 4 and 5 μм, where the two kinds of losses have slightingly small values according to the other kinds of losses in the optical fibres.

References

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