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Multilayer Silicon Oxynitride Strip Waveguide Mode Filter

Janardan Prasad[a]*and Vishnu Priye[b]

[a]*Department of Electrical and Electronics, IMS Engineering College, Ghaziabad, INDIA,*

[b]*Department of Electronics Engineering, Indian School of Mines, Dhanbad, INDIA.*
*jprasad3859@yahoo.co.in

Abstract

A four layered strip waveguide grown on silicon substrate and having a silicon oxynitride (SiON) guiding film with silicon oxide (SiO_2) as buffer and metal alongwith SiO_2 as cover is proposed and analyzed through transmission matrix formulation and effective index method. Dependence of polarization characteristic on waveguide parameter such as Aspect ratio (b/a) and hence effective index (n_{eff}) is discussed. It is shown that by changing the ratio from 0.5 to 2.0 an effective TM mode filter having passband in third communication windows of 1550 nm is achieved which have an insertion loss of less than 1dB/cm. It is also shown that by tailoring the number of layers TE mode filter can be realized.

Keywords - Optical filter, Silicon Oxynitride waveguide, Semiconductor waveguide, Strip waveguide, Transmission matrix method, Effective index method.

Introduction

A mode filter has an important role to play when communication is at zero dispersion wave length as the polarization mode dispersion becomes dominant. A metal clad waveguide inadvertently results in a TM mode filter (Khan and Jamid, 2003). However, for few applications such as quasi phase matched second order harmonic generation, electrooptic polymers, a TE mode filter (Jamid and Bader, 1988; Khan, 2001) becomes obvious choice.

For mode filter applications, multilayered waveguide shows more flexibility in design tolerance and fabrication as both film and buffer thickness can be controlled for optimal performance. In planar waveguiding structures of multilayered configuration, silicon oxynitride (SiON) (Ridder *et al.,* 1998; Germann *et al.,* 2000) has become increasingly important material for the realization of various integrated optical devices. A 4-layered planar waveguide structure having SiON as film and silicon oxide (SiO_2) as cover alongwith another layer of SiO_2 as buffer on silicon substrate has been analyzed (Prasad *et al.,* 2012) for realization of TE mode filter. For analysis transmission matrix method and Muller method (Anemogiannis and Glytsis, 1992; Mathews *et al.,* 2004; Priye *et al.,* 1998) have been employed.

In the present paper a multilayered SiON Strip waveguide fabricated on silicon-wafer (Horst *et al.,* 2000) through PECVD (Plasma enhanced chemical vapour deposition) process (Fadel and Voges, 2005) shall be analyzed for realization of mode filter. A SiO_2 layer has been grown in between the strip and the silicon-wafer to isolate the waveguide from silicon-wafer which is lossy at optical frequency as shown on figure 1. For practical realization of mode filter such two-dimensional configurations are to be investigated. To analyze two-dimensional waveguide using transmission matrix method it has been treated as superposition of two planar waveguides having boundaries at x and y-axes. Such approach is known as Effective index method (Marcatili, 1969; Knox and Toulios, 1970; Chiang *et al.,* 1996) in literature. In the present analysis method detailed in (Chiang *et al.,* 1996) shall be employed.

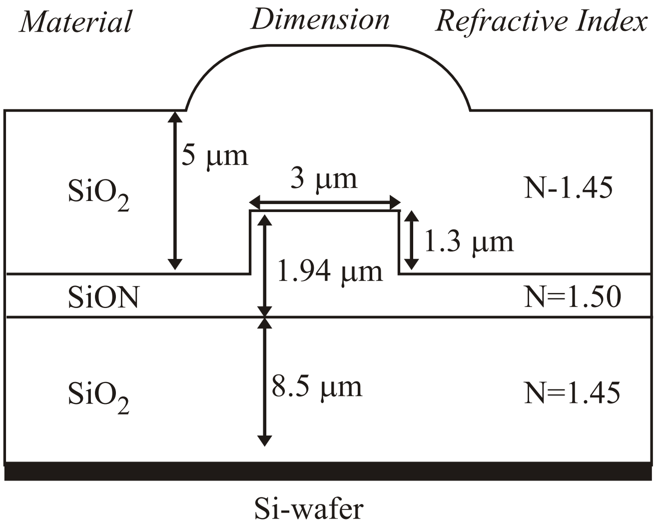

Figure 1: SiON strip waveguide fabricated originally for wave guidance.

Theory

For the strip waveguide to work as TM mode filter, an equivalent configuration shown in Fig. 2 is considered. Guiding film is made up of SiON having refractive index of *1.546* (in between 1.47 and 2.00) at *1550 nm*, buffer and cover layer of SiO_2 of refractive index *1.464* at the above mentioned wavelength. An additional cover of metal has been put above the SiO_2 cover as shown. Silicon substrate has the refractive index $3.47 - j10^{-4}$ at *1550 nm*. To apply Effective index method as outlined in Ref. Chiang *et al.,* 1996, strip waveguide is split into two equivalent planar waveguides as shown in Fig. 3 (a) and 3 (b).

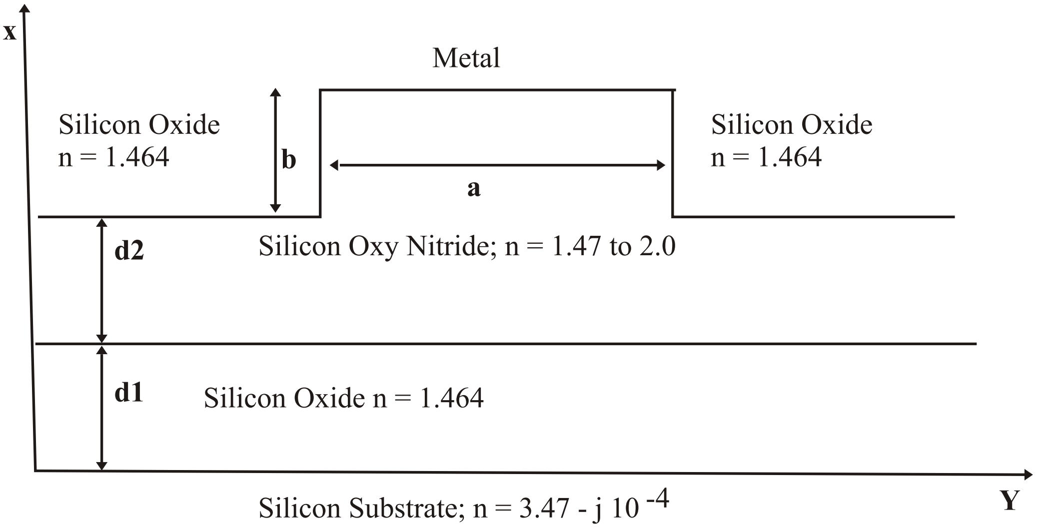

Figure 2: Geometrical representation of strip waveguide as modified for present application.

First of all configuration depicted in Fig. 3(a) is considered and numerical methods detailed in (Anemogiannis and Glytsis, 1992; Mathews *et al.,* 2004; Priye *et al.,* 1998) are applied. The complex propagation constant thus obtained is substituted as equivalent index n_x in the waveguide of Fig. 3 (b).

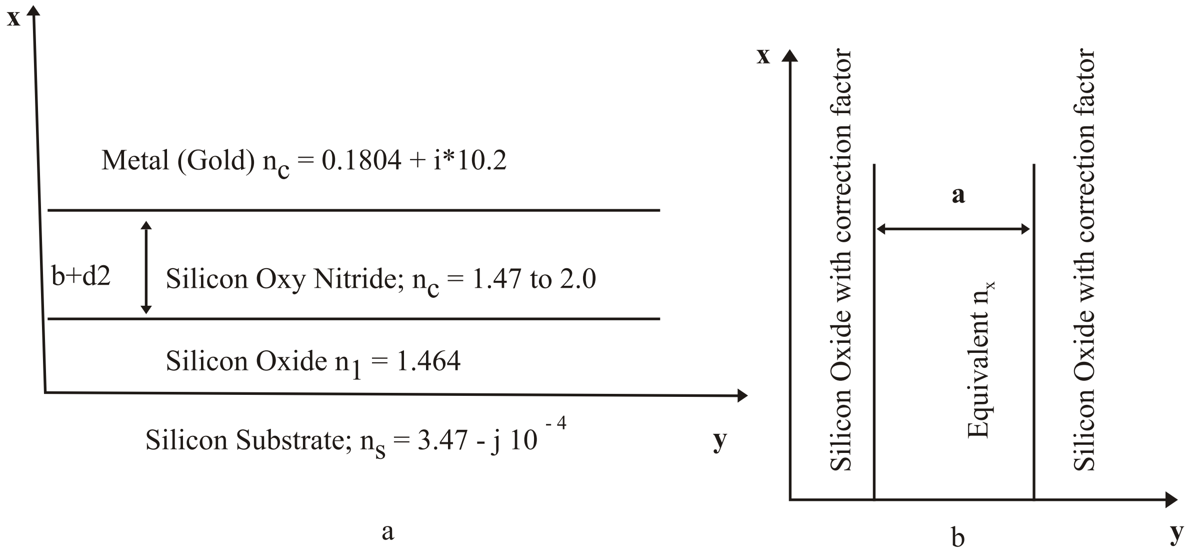

Figure 3: (a) and (b) shows the equivalent planar waveguides that are superimposed to obtain strip waveguide of Fig. 2.

Although rectangular waveguides rigorously support vector modes, for effective index method the equivalence is established as shown in Table 1.

Table 1: Equivalence of vector and quasi scalar modes in a two dimensional waveguide.

Vector Mode	Equivalent Scalar Mode
E^y_{11}	Quasi TE mode
E^x_{11}	Quasi TM mode

Correction factor (C.F) shown in Fig. 3 (b) is calculated using method given in Ref. Chiang *et al.,* 1996 and is given as :

$C.F = 1 - 1/(W_2+1)$

Where

$W_2 = bk\,(n_x^2 - n_1^2)^{½}$;

Using above mentioned C.F, refractive index of SiO_2 with correction factor indicated in Fig. 3 (b) is given as

$= n_1^2 - C.F\,(n_2^2 - n_x^2)$.

Result & Discussion

In Fig. 4 the normalized phase constant for the thickness of strip waveguide is shown. It can be observed that at lower value of normalized film thickness, the two modes are degenerate and hence will have different propagation behaviour. The loss in dB for 10 mm long waveguide, obtained from the imaginary part of the propagation constant is shown in Fig. 5. It shows that the loss incurred by TE mode is about 40 db less than that of TM mode.

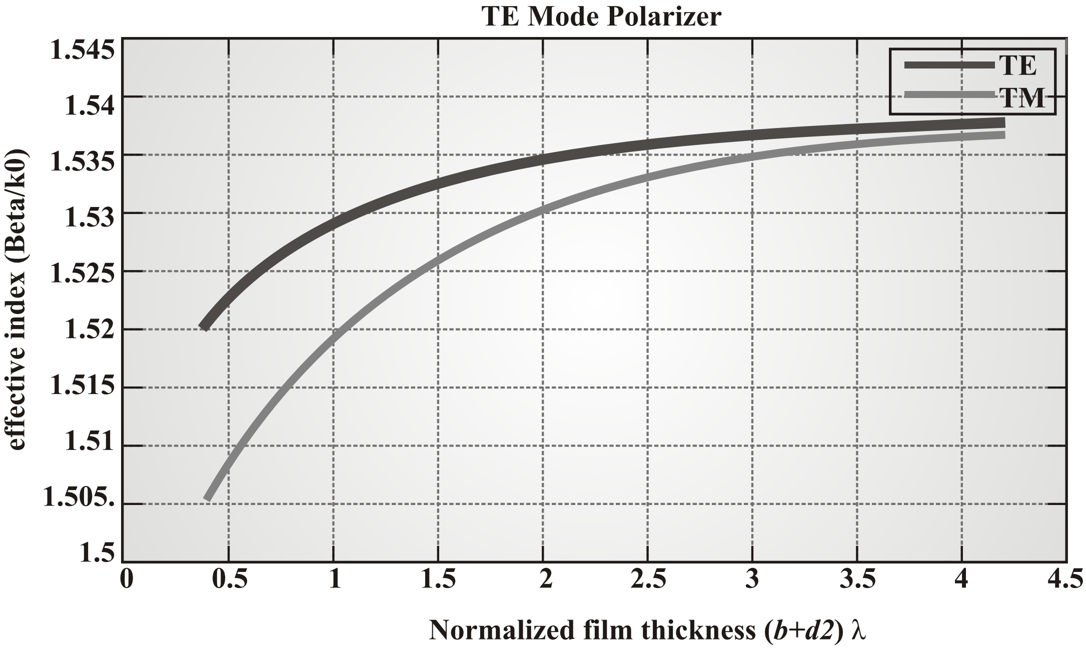

Figure 4: Normalized phase constant or Effective index with respect to normalized film layer (Upper curve represents TE mode and Lower curve represents TM mode).

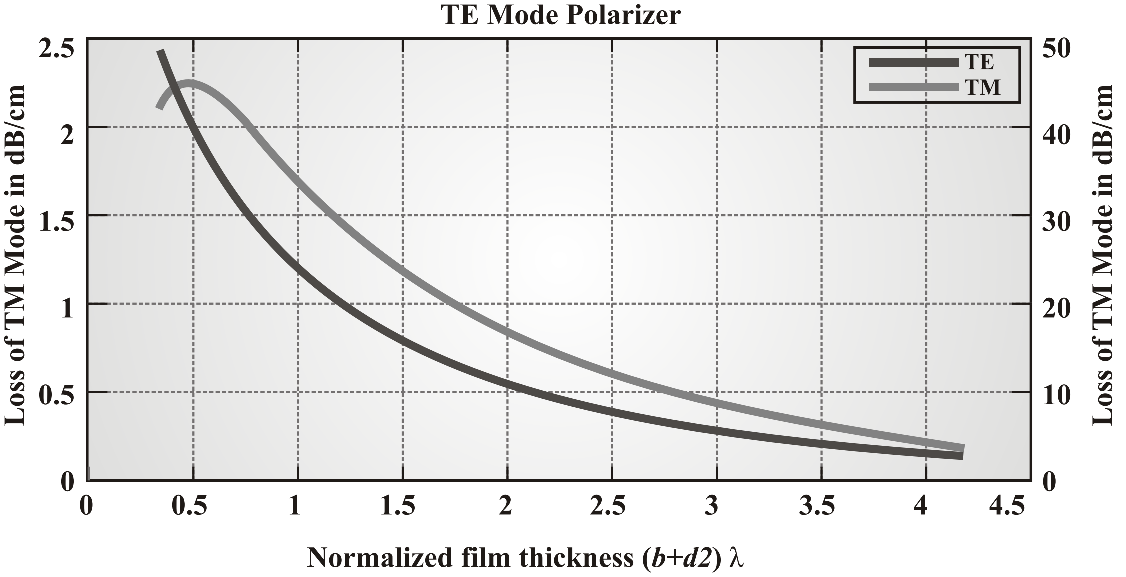

Figure 5: Loss with respect to normalized film layer (Lower curve represents TE mode and Upper curve represents TM mode).

Fig. 6 shows the variation of effective index with respect to normalized buffer layer. The behaviour shown here is different from planar waveguide structure. This behaviour may be due to the hybrid mode characteristic of the waveguide as both TE and TM modes are not pure but quasi in chracteristics.

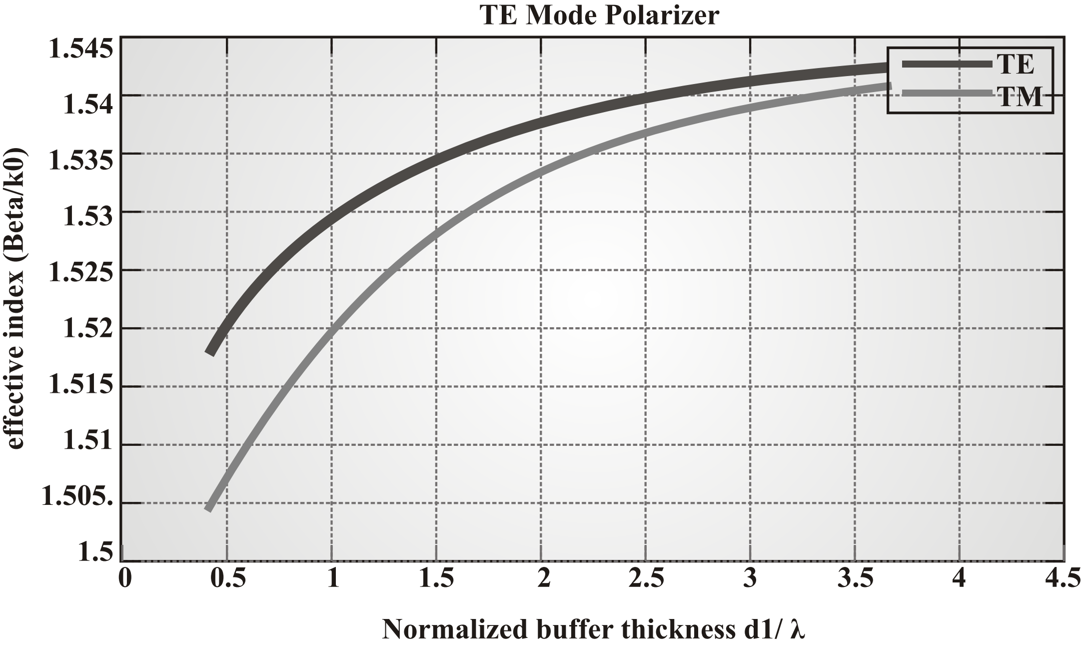

Figure 6: Effective index with respect to normalized buffer layer (Upper curve represents TE mode and Lower curve represents TM mode).

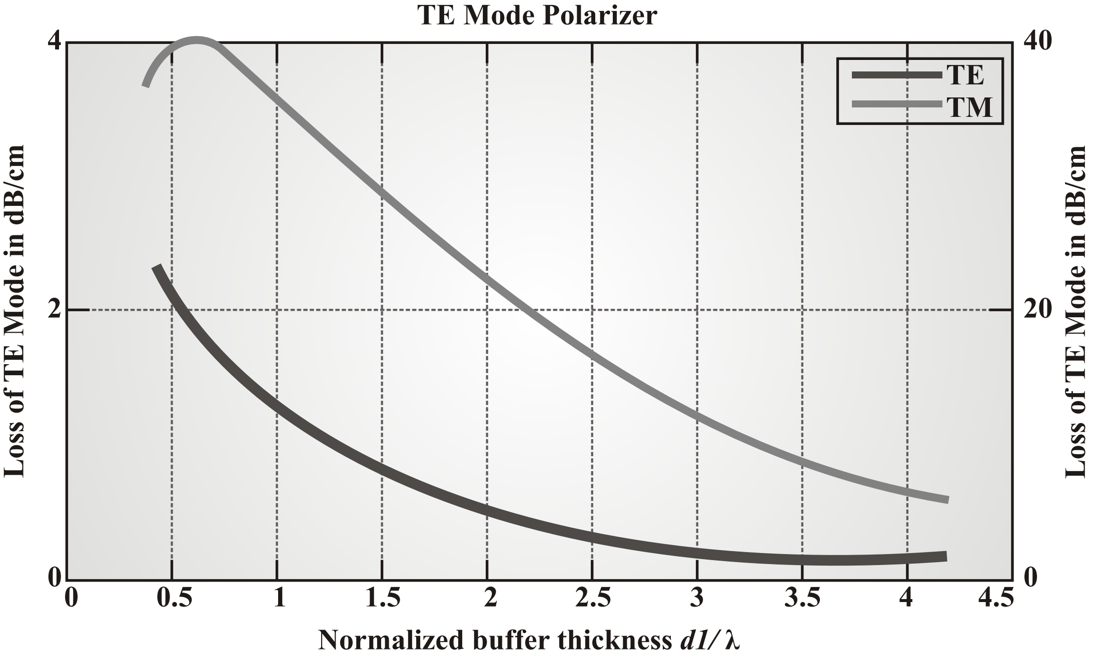

Figure 7: Loss with respect to normalized buffer layer (Lower curve represents TE mode and Upper curve represents TM mode).

The loss variation with normalized buffer thickness is shown in Fig. 7. The loss curves show that for normalized thickness of unity, the PER will be -35 dB and insertion loss of 1.2 dB.

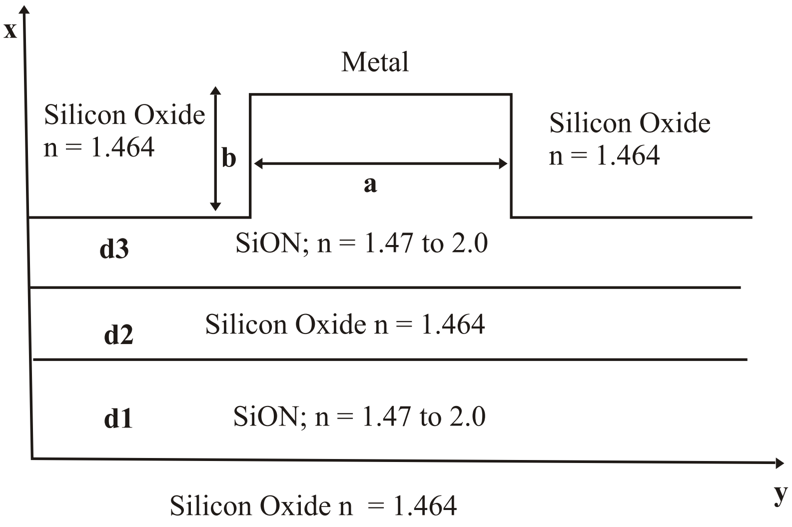

Figure 8: One extra layer of SiON added in between two SiO_2 layers.

The addition of one extra layer changes the waveguiding property of the strip waveguide. In this case most of the power is concentrated in the first layer of SiON, with same power leaking into the third layer of SiON (d_3). Hence the effect of metal layer is not predominant resulting in the properties of a TE mode filter.

Fig. 9 shows the loss characteristic of the waveguide of Fig. 8. Here for normalized buffer layer of 1.0 and (b+d3) of 2.0 µm, PER is about -64 dB and insertion loss 0.4 dB.

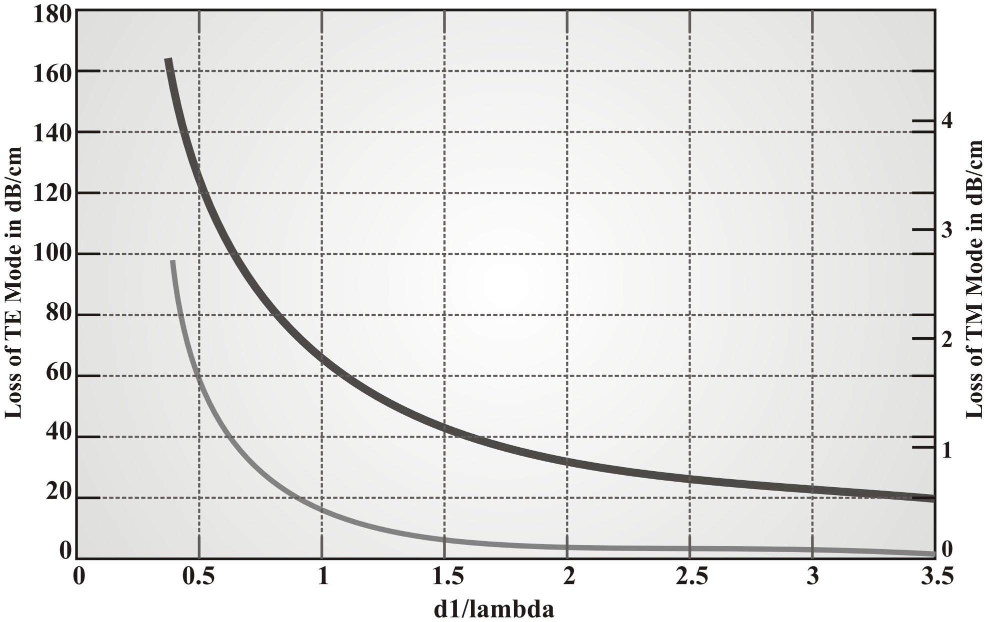

Figure 9: Loss characteristics of TE mode filter with normalized buffer layer. (Upper curve represents TE mode and Lower curve represents TM mode).

Conclusion

A multi-layered strip waveguide based TM mode filter consisting of SiON as guiding film, SiO_2 as buffer, SiO_2 alongwith a layer of metal as cover and silicon as substrate has been analyzed. It has been shown that the 4-layered strip waveguide configuration works as an efficient TM mode filter when film and buffer thicknesses as well as refractive index of SiON layer are judiciously chosen. The TM mode filter being reported has a TE passband at 1550 nm, polarization extinction ratio of -35dB and insertion loss of less than 1.2 dB. In addition to above if an extra layer of SiON is added, the waveguide behaves as a TE mode filter with PER – 64 and insertion loss 0.4 dB.

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