Slotsuppression of Scattering Loss in the Side Wall of Bent Slot Waveguide

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Abstract. With the higher requirements of advanced integrated circuit technology, waveguides can propagate electromagnetic waves with higher frequencies, such as millimeter waves and centimeter waves, and have a large power capacity, which makes waveguides a common transmission line in the microwave band. In this experiment, based on the research of the curved slot waveguide, the method of suppressing the scattering loss of the side wall is studied. The wave optics module is used to model the optical waveguide, and the mode of the designed curved slot waveguide is analyzed, and the thickness of each layer of the optical waveguide is optimized according to the material characteristics to reduce the influence of the high refractive index substrate and reduce the curvature of the side wall Absorption of scattering loss to avoid the influence of resonance. The curved slot waveguide curved microring resonator and the curved slot waveguide racetrack microring resonator are studied, and the device performance parameters are simulated and analyzed. In view of the above-mentioned shortcomings of the prior art, the purpose of the utility model is to provide a sidewall scattering loss based on a curved slot waveguide and a preparation method. The side scattering characteristics of the waveguide multilayer memory are experimentally studied. The results show that the distribution of the scattered light intensity from the side of the waveguide along the propagation direction of the guided light exhibits an exponential decay law, and its attenuation constant is proportional to the information symbol density, and the curved slot used for recording information increases and grows.

Keywords: Curved Slot, Scattering Loss, Waveguide Sidewall, Waveguide Storage

1. Introduction
The slot waveguide is found in experiments that when two silicon waveguides with a small width are close to a nanometer distance, the light is strongly confined in the low refractive index slot, showing obvious slot characteristics, this is the slot The origin of the name of the waveguide [1]. The thermo-optical coefficient of silicon material is relatively large, and most of the earliest optical modulators and optical switches are based on the thermo-optical effect [2]. The total internal reflection that we are familiar with is usually the propagation characteristic of light waves in the medium, the
refractive index of the material in the middle is relatively large, and the refractive index of the surrounding materials is relatively small [3]. Due to the unique physical characteristics and good application prospects of slot waveguides, many researchers are paying more and more attention to slot waveguides [4].

Many new functional optical devices based on single-slot or multi-slot waveguides have been developed, such as high-speed compact digital silicon optical switches (Silicon Optical Switch, SOS) in the field of optical communications and high-speed optical sensors in the field of optical sensing. Novel Biochemical Sensor (NBS) with sensitivity and low detection limit [5]. In addition, slot waveguides can also assist other devices to work together. Suppression application of side wall scattering loss. There are two stationary communication stations, the linear distance between each other is z [6]. Due to the different air pressures at various points in the troposphere, turbulence is generated, resulting in unequal distances from each point in the troposphere to the ground; at the same time, for ease of analysis, when constructing the channel geometric model, the troposphere is regarded as a differentiable curve, and the scatterers are random. The ground is distributed on the curve, and the electromagnetic beam is transmitted to the receiving site through the scattering of various scatterers [7-8].

The side wall scattering means that the beams scattered when passing through the scatterer will shoot in all directions, and the energy of the outgoing beam will decrease with the increase of the scattering angle. According to the theory of turbulent incoherent scattering, the energy of the scattered beam is the largest at the angle of specular reflection. At other angles, the beam energy decays exponentially as the angle between the scattering angle and the reflection angle increases [9]. The tangent plane of this point on the curved surface can be regarded as the reflecting surface, and the normal of the curved surface at this point is the normal of the human wave and the reflected wave. The scatterer is modeled as a sphere, and the scattered beams radiate outward from every point on the surface of the sphere, and the directions of the scattered beams are perpendicular to the surface of the sphere [10].

2. Algorithm Optimization

2.1 The Shift Formula of Side Wall Scattering Loss

The scattering loss of the side wall can generally be expressed as the following formula:

$$P_r = A_1 P_1 G_{10} G_{20} \left( \frac{1}{4\pi} \right)^2 \int \frac{g_1 g_2 \delta}{(r^2)^2} dV$$\hspace{1cm}(1)

After a complicated integration process, the end power term related to the bearing term can be obtained:

$$U = \frac{2\pi \theta_{20}}{m c_h \exp} \left\{ -\frac{\phi_{20} - \phi_{2m}}{\theta_{20} - \phi_{2m} - \phi_{20} \theta_{20}} \right\}$$\hspace{1cm}(2)

According to the above-mentioned teachers, m is the negative power exponent of the scattering angle of the scattering cross section; $\phi_{10}$, $\phi_{20}$ are respectively the horns at the end of the slot, the quantity related to the horizontal wave width, and the expressions of other variables are as follows:

$$\phi_{2m} = \frac{s_1 \theta_{10}}{1 + \frac{m \theta_{10}^2}{\theta_{10}}}$$\hspace{1cm}(3)

$$C_h = \sqrt{1 + \frac{\theta_{10}^2}{m \theta_{10}^2} + \frac{\phi_{20}}{\phi_{2m}}}$$\hspace{1cm}(4)
\[ B_{h2} = \sqrt{1 + \frac{2 \left( \frac{\varphi_{10}}{\varphi_{12}} \right)^2}{m + 2 \left( \frac{\varphi_{11}}{\varphi_{10}} \right)^2}} \]  

(5)

\[ s_1 = \frac{\theta_{20}}{\theta_{10}} \]  

(6)

When the bending angle is not accurate, the path transmission loss relative to the forward scattering has the following reasoning formula:

\[ L_{db} = 10 \log \frac{\theta_{20}}{c_n} \]  

(7)

The working principle of the slot waveguide is based on the discontinuity of the electric field intensity at the high refractive index contrast interface. From Maxwell's equation, we can know that due to the continuity of the normal vector \( \mathbf{D} \) at the point displacement at the interface of the two media, the corresponding power plant intensity \( \mathbf{E} \) must be continuous and has a higher amplitude on the low refractive index side. That is, at the interface between the two regions where the dielectric strength is \( \varepsilon_2 \) and \( \varepsilon_1 \) in constant, the relationship between the appropriate amount of electric displacement \( \mathbf{D} \), power plant strength \( \mathbf{E} \) and refractive index is the continuity of the electric displacement vector, expressed in the form of power plant, and After bringing in the refractive index, you can write:

\[ n_2^2 E^N_x = n_1^2 E^H_x \]  

(8)

Usually the size of the slot waveguide (the distance between the high refractive index plates) is comparable to the attenuation length of the fundamental mode in the guided wave structure, so the normal direction electric field at the high refractive index contrast interface has a strong inside the slot. The energy density in the slot layer is much higher than that in the high refractive index area. The propagation of light waves is due to total internal reflection and has no interference effect, so the slot waveguide will show very low wavelength sensitivity. This characteristic makes the slot waveguide have a very unique application range and realize high-performance devices.

3. Modeling Method

3.1 Numerical Simulation of Curved Slot Waveguide

In the two-dimensional case, the right-angle components of the curved slot waveguide can be divided into two groups independently, A and B respectively. When the FDTD is discrete, the algorithm model is as follows:

Group A algorithm model:

\[ \frac{\partial H_z}{\partial y} = \varepsilon \frac{\partial E_x}{\partial t} + \sigma E_x \\
\frac{\partial H_z}{\partial x} = \varepsilon \frac{\partial E_y}{\partial t} + \sigma E_y \\
\frac{\partial E_y}{\partial y} = \frac{\partial E_x}{\partial x} = \mu \frac{\partial H_z}{\partial t} \sigma_m H_z \]  

(9)

Group B algorithm model:

\[ \frac{\partial H_z}{\partial y} = -\mu \frac{\partial E_x}{\partial t} + \sigma_m H_x \\
\frac{\partial E_x}{\partial x} = \mu \frac{\partial H_y}{\partial t} \sigma_m H_y \\
\frac{\partial E_y}{\partial x} = \varepsilon \frac{\partial E_z}{\partial t} \sigma E_z \]  

(10)
The time-domain-based finite difference method is different from any previous method. It is based on the principle of difference. It directly starts from the Maxwell curl equation that summarizes the general law of electromagnetic field, and converts it into a system of differential equations, which can be combined in a certain volume. The data of continuous electromagnetic field is sampled in time. Therefore, it is the most primitive, essential and complete numerical simulation of electromagnetic field problems, and it has the widest applicability. Because the FDTD method model is simple, intuitive and easy to master. It does not require any Maxwell derived equations, avoiding the use of more mathematical tools, making it the simplest of all electromagnetic field calculation methods.

4. Comparative Analysis of Results

4.1 Side Wall Scattering Loss and Its Relationship in Curved Slot Waveguide

Figure 1. Loss parameter curve of curved slot guide wall based on optimized parameters

As shown in Figure 1, when other parameters remain unchanged, changing the curved slot degree W can adjust the flatness of dispersion. At long wavelengths, the dispersion coefficient D is more sensitive to the change of the waveguide width W, and the zero dispersion point and slope of the dispersion curve can be effectively adjusted. At the same time, the loss of curved slot waveguides can be effectively managed by changing the waveguide width. In the process of optimizing the scattering loss, changing the height of the middle GBH715 can flexibly adjust the fluctuations of the curve of the scattering loss of the entire curved slot, especially when the loss offset is large, the high-order loss coefficient is reflected, so In the ultra-flat coefficient distribution, the influence of high-order loss rate on the four-wave mixing effect can be ignored; on the other hand, with ultra-low and flat dispersion, the resonant cavity has equally spaced resonance peaks, and it is also connected with the cascade The new frequency components of the four-wave mixing coincide to produce frequency combs with almost the same spacing, thereby enhancing the four-wave mixing effect. Therefore, it is necessary to design a waveguide with low and flat abnormal bending conductance and strong loss for high-quality bending output.
Figure 2. Changes in the width of the curved slot

It shows that when the slot width increases, the effective refractive index of the mode decreases monotonously, and its changing trend is different. Based on the analysis in Figure 1, at first, as the width of the slot increases monotonically, it can be concluded that the intensity of the light field distributed in the slot area increases, because the refractive index of the slot area is significantly lower than that of the silicon waveguide area, and the effective refractive index follows the curvature. Therefore, the effective refractive index of the mode decreases; when the width of the slot is greater than a certain value, the effective refractive index of the mode continues to decrease. It can be concluded that the scattering loss of the slot guide wall is mainly distributed in the slot with lower refractive index. Because of the monotonous downward trend in the area and the over-cladding area, the intensity of poison in the slot area decreases.

4.2 Measured Data Analysis of Algorithm Model

| Line          | Route trend 1 | Route Trend 2 |
|---------------|---------------|---------------|
| D/KM          | 104.33        | 27.15         |
| ITU-S17       | 205.12        | 232           |
| NMS-195       | 205.12        | 319           |
| Method prediction | 205.37      | 237           |

The calculation results can be seen from Table 1. The method proposed in this paper is more accurate when the curvature is small. When the communication distance d is 27.15km, the estimated error loss of ITU-S17 is 35dB, the estimated error of NMS-195 is 8dB, and the error of the method proposed in this paper is only 6dB; and when the link distance is increased to 107km, ITUR617 can be accurate To estimate the scattering loss, the error of the estimation method of NB101 is only 2dB, but because the error of the measured data of the relevant angle has a much greater influence on the calculation result than when the scattering distance is short, the error of the estimation method proposed in this article is 6dB, and the estimation error is relatively large. Large, but still within an acceptable range. Set the geometric center spacing of two different curvatures to 25mm and 50mm, respectively, the elevation angle of the transmitting antenna is 1 degree, and the cloud height is 2km, regardless of the influence of the distance between the slots on the distribution of the scatterers. Therefore, under different conditions, the scattering loss of the side wall is closely related to the distance between two different curvatures.

4.3 The Characteristics of the Scattering Loss of the Waveguide Side Wall
The scattering loss of the guide side wall of the curved slot wave in the form of a waveguide defect is coupled with the radiation mode. The experimental study of the side scattering characteristics of the waveguide memory leaks the waveguide in the form of scattered light, and is received by the photodetector to read the data. The curved slot wave leaks from the end of the waveguide. In order to improve the performance, data readout sensitivity and GBM of the waveguide multilayer thick storage device, it is necessary to understand the relationship between its side scattering characteristics and structural parameters. In this way, two situations can be avoided by changing the relevant parameters. The transmitted light energy is converted into a scattered curved slot wave. The wave is too small, most of the conduction leaks from the end of the waveguide, the side scattering efficiency is low, the energy conversion is too fast, and the transmitted light has not At the end of the waveguide, it is attenuated to close to zero, and the scattered light emitted by the defect at the end of the waveguide is too weak, which affects the reading of data. In this paper, the intensity distribution of the lateral scattered light of the waveguide defect is given through experiments, and the influence of the waveguide surface defect density and recording conditions on the scattering loss characteristics is studied.

The side wall scattering loss of the curved slot waveguide is simulated and designed, and the preparation of the slot waveguide is experimentally studied. In order to reduce the curvature of the slot, the working wavelength is selected as 20nm near infrared band. The single mode of the slot waveguide is calculated. The conditions are met, with the goal of improving the sensing sensitivity, and the structural parameters of the slot waveguide height, width and slot width are optimized. A new type of PMEF material is introduced to prepare soft molds, which improves the yield of optical waveguide devices. The soft embossing process fabricated the curved slot waveguide sidewall sensor. The fabricated waveguide is based on a higher aspect ratio and a lower residual layer.

5. Result

With the rapid development of society, people's demand for information continues to grow, so that the corresponding communication capacity and signal exchange rate must be increased day by day. Among them, especially the excellent control ability of the curved slot waveguide structure in terms of dispersion and nonlinearity makes it one of the most popular directions in the research of photonic integrated devices. In the integrated device based on the suppression of the scattering loss of the side wall of the curved slot waveguide, the mode (effective refractive index) of the entire waveguide structure will be coupled with the change of the wavelength, so as to realize the function of adjusting the dispersion; it can also be used at a lower refractive index. The slot area realizes the limitation of the bending of the waveguide, which enhances the nonlinearity of the waveguide device. Therefore, the advantages of slot waveguide structure in bending and nonlinearity can achieve some high-performance nonlinear effects and applications. At the same time, the research and analysis of the dispersion and nonlinear control principle of the slot waveguide, preliminary results show that a reasonable design of the slot waveguide structure and materials can optimize the design of various waveguide structures required, so that the waveguide has a flat and low dispersion curve and High nonlinearity is conducive to the generation of nonlinear effects. This work provides a design basis and a theoretical basis for the next step of using the nonlinear effect in the slot waveguide for signal processing and designing a reasonable waveguide structure.

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