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A SIMPLE THREE BRANCH OPTICAL POWER SPLITTER DESIGN BASED ON III-NITRIDE SEMICONDUCTOR FOR OPTICAL TELECOMMUNICATION

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ABSTRACT

We propose a simple design of 1×3 optical power splitter which uses gallium nitride (GaN) on sapphire. The design consists of widely used large cross section input rib waveguide, a rectangular multimode interference (MMI) structure, and three-branch rib waveguides. The MMI structure is selected since their attractive performances, such as compactness, low excess loss, wide bandwidth and ease to fabricate. The power splitter is designed for the third telecommunication window, i.e., λ = 1.55 μm. Optimization of the geometrical structure parameters for the design is conducted theoretically utilizing 3D FD-BPM method. It is found that the power splitter exhibits excess loss of 0.46 dB and imbalanced of 0.001 dB at λ = 1.55 μm for n_{TE} = 2.279 ± 0.001 and n_{TM} =2.316± 0.001, respectively. It means that there is a potential application of the proposed GaN based power splitter structure in the future.

Keywords: GaN; MMI structure; Optical power splitter; Optical communication; Three branches

1. INTRODUCTION

Power splitter has many potential applications in optical communications. Power splitter also act as a fundamental element in constructing photonic integrated circuit. This structure can distribute light to optical components that consume optical power. In addition, by means of the electro optic effect, these structures can serve among other as switchs, where the optical signal is changing the propagation direction because of the refractive index decreases when a current is injected into one output branch (Malek et al., 2009) and Mach-Zehnder interferferometer which is essential for high quality signal transmission in high speed, long haul optical fiber telecommunication (Ogawa et al., 2013). Multi branch optical power splitter is a promising device for a large matrix switch because it has a higher ports per unit length than the two branch waveguide switch. It means that if we use a three branch or a four branch switch as a unit device in the matrix switch instead of a two branch switch, we can increase the matrix size without increasing the number of stages.

So far, many types of optical power splitter based on Y branch structure device have been

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developed (Coi, 2003; Oh, 2011; Wang et al., 2014). From fabrication point of view, the branching point, where the waveguides start to separate, is not easy to fabricate. To overcome this problem, the self and multi imaging effect in optical multimode waveguides have been used to perform 1-by-N optical power splitting. Such devices are refrered multimode interference (MMI) optical power splitters. In this design the sharp edges near the branching points are avoided, therefore resulting a more simple process design. In addition, the MMI power splitters are potentially shorter than other branching-type design (Soldano et al., 1992).

Power splitters based on a multimode waveguide section between the input and output waveguides have been proposed and fabricated earlier. Using various optoelectronic materials, some researchers have been developed power splitter based switches, among others are InP/lnGaAsP optical integrated MMI switches (Singh et al., 2009) and InGaAsP-InP MZI optical space switch (Soldano, 1994). The others have been made on SOI, polymer, and sol-gel (Rasmussen et al., 1995; Fardad, 1999; Tao et al., 2008; Prajzler et al., 2015). However there has been very little work done on GaN power splitter based photonic device for application in optical communication, among others are directional coupler, Y branch power splitter and Mach Zehnder Interferometer (Stolz, 2012; Hui et al., 2003; Purnamaningsih et al., 2014; Retno et al., 2014; Arviza et al., 2014). GaN semiconductors have attracted considerably interest since they have a relatively high refractive index which enables the fabrication of compact guided wave circuits. They are also transparent in the infrared regions; make it possible for use in combination with fiber optics and Si-based single-photon detectors. Moreover, nitride based device are the most environmentally friendly among others compound semiconductors.

As far as we know there are no multibranch power splitter design based on MMI structure using GaN materials. Therefore in this paper we will demonstrate the design of 1×3 power splitter using GaN on sapphire. The design based on a simple multimode interference (MMI) structure since their attractive performances, such as compactness, low excess loss, wide bandwidth, and ease to fabricate.

2. PRINCIPLE OF MMI STRUCTURE

MMI structure device is useful photonic component since it can reproduce images of an input beam at periodic intervals along the propagation direction. This is due to interference of the waveguide modes. This self-imaging principle (Soldano, 1995; Ulrich, 1975) causes the input field to be reproduced as either single or multiple images at regular intervals along the length of the MMI device. The self-image theory is usually used to determine the geometrical parameters of the MMI section and the positions of the input and output waveguides. A MMI structure device is a waveguide designed to support a large number of modes. In order to launch light into a multimode waveguide, waveguides are connected at its beginning, while for recovering light from that multimode waveguide, a number of output waveguides are placed at its end. Such devices are known as N×M MMI couplers, where N and M are the number of input and output waveguides, respectively.

To describe self imaging phenomena in multimode waveguides, the finite difference beam propagating method (BPM) is one of the most powerful techniques. This method is done entirely in the frequency domain and can be used to investigate both linear and nonlinear lightwave propagation phenomena in axially varying waveguides (Yamauchi, 1991). Finite difference BPM solves Maxwell's equations by using finite differences in place of partial derivatives. In this sense BPM is computational intensive, it provides not only the basis for numerical modeling and designs, but it also provides an understanding of the multimode interference mechanism (Jenkin et al., 1992).

3. OPTIMAL DESIGN OF GEOMETRICAL PARAMETERS OF 1×3 POWER SPLITTER

In this section we will describe the design of a 1×3 optical power splitter. Our proposed GaN power splitter design based on a combination of a conventional rectangular MMI structure (Soldano et al., 1995) and rib waveguide. We use the OptiBPM software which use a slowly varying envelope approximation to simulate the light propagation through 1×3 GaN on sapphire power splitter design. We use the finite difference beam propagation method (FDBPM) to calculate the field propagation through the structure since all the guided and non guided modes are automatically included in the calculations. Therefore, we can calculate the coupling between the modes propagating in the output branch waveguide accurately by the FDBPM. Parameters of the design are used from previous work; GaN active layer grown on high temperature/low temperature AlN/GaN buffer layers. The buffer layers are 300 nm AlN and 200 nm AlGaN, respectively (Saraswati et al., 2012). The cross section of the layers is shown in Figure 1.

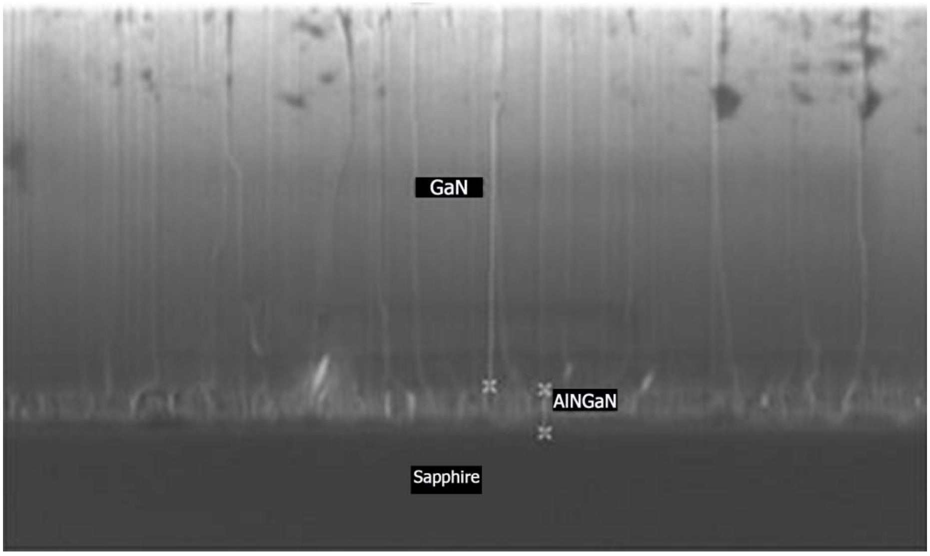

Figure 1 GaN/Sapphire layers (Saraswati, 2012)

The power splitter is designed for the third telecommunication window, i.e., λ = 1.55 µm. The design consists of widely used large cross section rib waveguides, a rectangular MMI structure, and three branching rib waveguides. The input rib waveguide cross section is shown in Figure 2a. The input waveguide and one of the output waveguides are aligned to the longitudinal axis of the device. The outer two waveguide centers are positioned symmetrically at either side of the central axis. The refractive index of the layers are n_{TE} = 2.279 $\pm$ 0.001 and n_{TM} = 2.316$\pm$ 0.001, respectively, which is obtained from previous work (Saraswati et al., 2014). Using 3D-BPM we deduced the schematic design presented in Figure 2b. The optimum optical power splitter design obtained through the optimization of several parameters such as width and length of every section of design.

The design was carried out in stages. Firstly, a rib waveguide as the input waveguide is connected to MMI waveguide section and at the end of the multimode section; the light is coupled into three branching output rib waveguides. W_{MMI} and L_{MMI} are the width and length of the multimode waveguide section respectively. To improve the resolution of simulation in the MMI region, the branch section was removed from the structure during numerical simulation to obtained the best width and length of MMI structure. Through simulation it was found a spacing of > 10 µm is needed to avoid significant coupling between the output waveguides. A center to center of 15 µm was then choosen to ensure single mode propagation through 4 µm output branch waveguides.

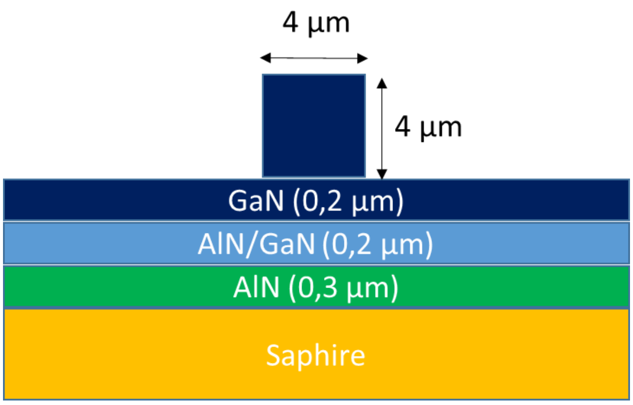

Figure 2a Cross section of input power splitter

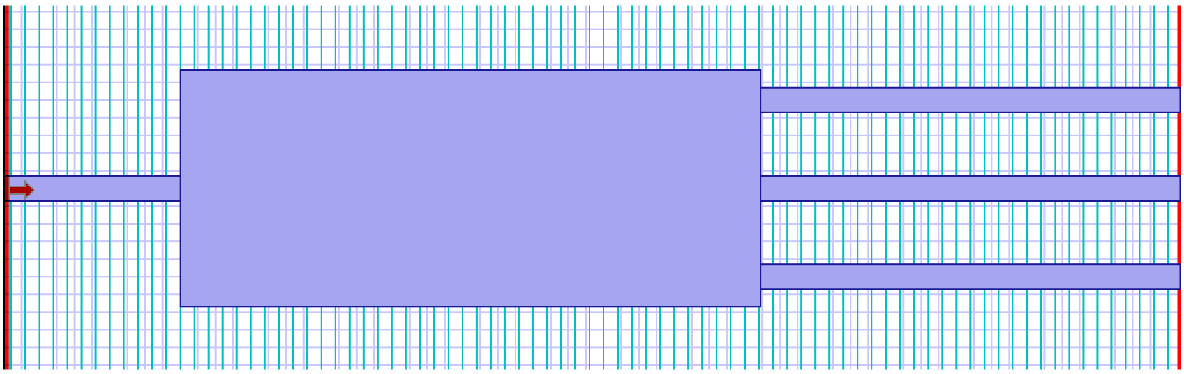

Figure 2b The proposed 1×3 optical power splitter

This results are in accordance to the previous research (Ulrich & Adele, 1975). Their analysis showed that stated that the distance between neighboring output waveguides at the end of the multimode section is W/N. They showed that by assuming that the propagation constant of the optical modes depend quadratically on the mode number, the shortest length of the multimode section may be calculated approximately by:

$$L_{MMI} = \frac{n \ W_{MMI}^2}{N\lambda} \tag{1}$$

In this case $N = 3$, is the number of splits. By applying Equation 1, we can calculate and predict the length of MMI structure as a function of the width, waveguide refractive index, and wavelength. In this paper the width and thickness of input and output rib waveguides are 4 µm and support only single mode propagation. The final power splitter design is 2000 µm long and not more than 40 µm wide. This result is achieved by adjusting the design dimension to give the minimum imbalance and lowest excess loss. We used FDBPM method and found that 3-D FDBPM simulation gives a better theoretical prediction than 2-D-FDBPM.

4. RESULTS AND DISCUSSION

The power splitter design was carried out using OptiBPM, the simulated single mode structure at 1.55 µm wavelength and its map of optical field is shown in Figure 3, while the output is represented in Figure 4. Red and green color in Figure 3 represent the highest and the lowest optical field respectively.

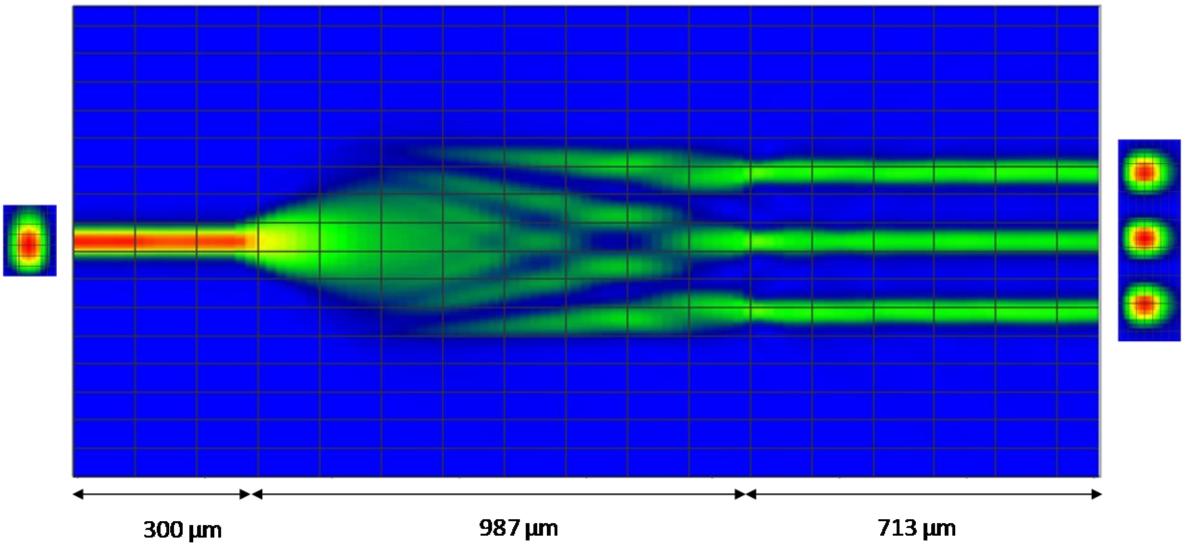

Figure 3 Optical intensity field distribution of the proposed 1×3 Power Splitter, when total length L= 2000 µm and W_{MMI}W= 40 µm

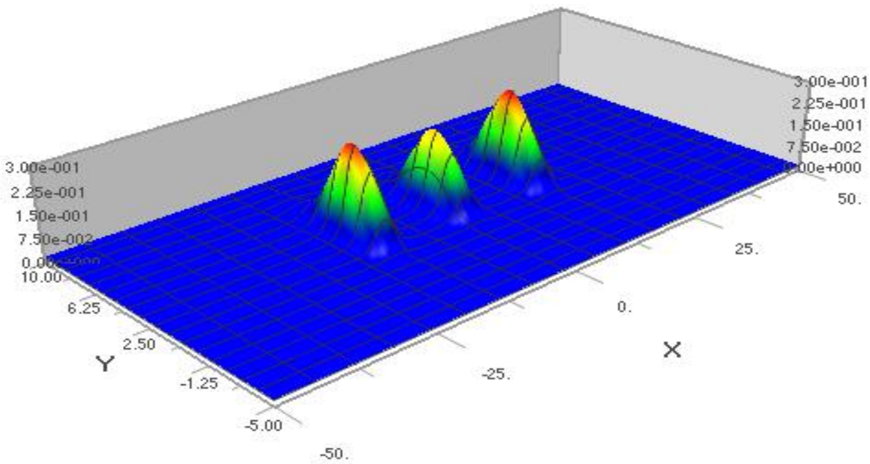

Figure 4 Optical intensity field distribution at the splitter output

Figure 4 shows the optical intensity field distribution at the end of the power splitter output, showing the uniformity of the power in the three branches. It is shown that the device achieves a uniform splitting ratio of 30% in each branch. This result is close enough to the ideal value of 33.3% and does not change over the propagation distance from the splitter output. In this design we obtained the best width for three branch W_{MMI} = 40 µm, and the corresponding length of the multimode section is L_{MMI} = 987 µm for TE polarization. Figure 5 shows the relative optical power as a function of propagation distance. It shows that the relative optical power decreases slowly by the increase of propagation distance.

The relative power obtained at output ports is 0.9 at a wavelength of 1.55 µm. This value is the total relative output power of three ports.

The key performance of power splitters are excess loss and imbalance. Therefore we calculate both excess loss and imbalance for the width W_{MMI} and length L_{MMI} adjusted to give the lowest loss.

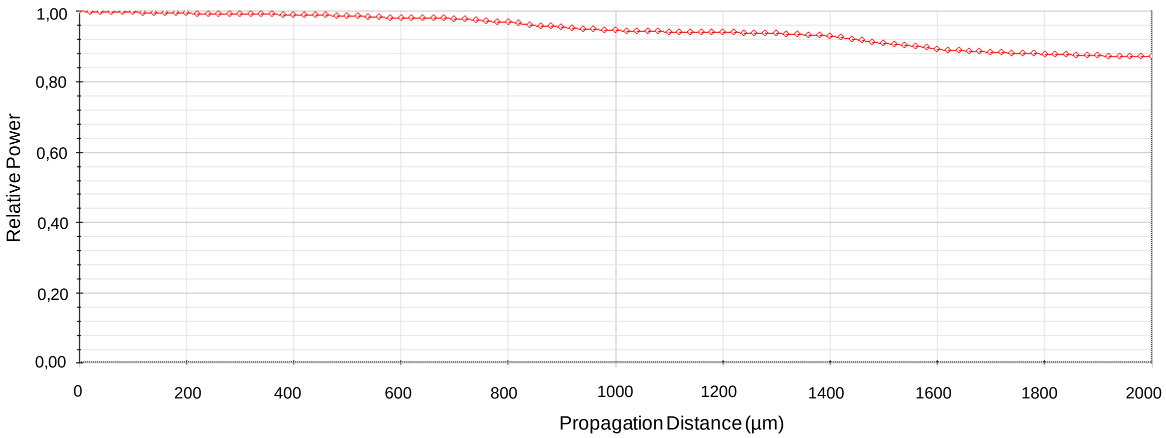

Figure 5 Relative power distribution along propagation distance

The excess loss of the splitter defined as (Wei et al., 2001):

$$\text{Excess loss} = -10log_{10}\left({}^{P_{out}}/_{P_{in}}\right) \tag{2}$$

where P_{out} is the total output power and P_{in} is the input power. We obtained the calculated excess loss at 0.46 dB. The next key performace of power splitter is imbalance, defined as follows (Besley et al., 1998):

$$\text{Imbalance} = -10log_{10}(1-\sigma_p) \tag{3}$$

where σ_p is the standard deviation of the power of the output ports normalized to one third of the input power. We obtained a very small Imbalanced of 0.01dB. It means that the proposed GaN based power splitter has a potentials for future optical telecomunication device.

5. CONCLUSION

In this paper we have proposed a simple three branch power splitter using GaN on sapphire for the third optical communication wavelength, λ = 1.550 μm. FD-BPM has been used to obtain the optimal geometrical parameters for the MMI waveguide section as well as the input and branching waveguides. A uniform power splitting over three output rib waveguides is obtained with 987 μm long and 40 μm width MMI structure respectively. Although the proposed design is promising to be applied in the future, there is still much work to be done before it become practical.

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