Low loss fiber to chip connection system for telecommunication devices

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We present a method for low loss coupling of multiple fibers to optical waveguides. Simultaneous alignment of multiple fibers is done by placing the fibers in a V-groove array. Coupling efficiency can be enhanced by placing a high numerical aperture (HNA) fiber (MFD 4 µm) between the standard telecom fiber and a horizontal tapered waveguide. The splicing loss between the standard telecom fiber and the HNA fiber was less than 0.2 dB. The coupling loss between the HNA fiber and the tapered waveguide channel was simulated and lower than 0.25 dB for perfect alignment. This gives a total coupling loss from a standard telecom fiber to the waveguide channel of less than 0.6 dB.

Introduction

In modern telecommunication data-signals are transported over optical fibers and processed in Integrated Optical Circuits (IOC). To be able to process the light in the IOC it has to be coupled from the fiber into the IOC (polarization independent). To be commercially interesting both the loss and the price of this coupling should be low. Therefore a simple fabrication technique and coupling of multiple fibers at once is desirable.

The coupling that was realized is a coupling between standard telecom fibers and optical waveguides. The telecom fibers have a Mode Field Diameter (MFD) of 10 µm. The dimensions (h x w) of the waveguides are 0.82 x 3.25 µm and they consist of a SiON core and a SiO2 buffer and cladding. This results in an optical field as given in figure 1. As can be seen the MFD of this field is much smaller than 10 µm.

To let the dimensions of the field in the fiber match the dimensions of the field in the waveguide, the dimensions of the field in the waveguide are increased by tapering the waveguide. Because it is very difficult to increase the dimensions of the field in the waveguide to a MFD of 10 µm the MFD of the fiber has to decrease.

This is done by splicing a fiber with a smaller MFD (4 µm) to the telecom fiber.
Because multiple fibers have to be aligned to the waveguides simultaneously, the fibers are placed in a V-groove array. Schematic this entire system looks as in figure 2.

Realization

Splicing fibers

A fiber with a MFD of 4 µm (Thorlabs U-HNA fiber) is spliced to a telecom fiber (both fibers have an outer diameter of 125 µm). During this splice process the core of the HNA fiber diffuses into the cladding, which results in an adiabatic tapered coupling between the telecom fiber and the HNA fiber. [2][8][9]. This adiabatic tapered coupling converts the spot size in the fiber from 10 µm to 4 µm. The process is optimized (optimization of the number of arc discharges and duration of these discharges), by measuring in situ the loss of two splices during the splice process (during the measurement only one of the two splices can be optimized). Schematically this is given in figure 3. An optimum was found at 3 arc discharges of 2000 ms each. Reproducible losses as low as 0.2 dB/splice were measured.

FMC and tapered waveguide

The tapering of the optical waveguide is done only in horizontal direction. There is no tapering in vertical direction because that makes the fabrication process for this taper more complex. Between the HNA fiber and the tapered waveguide there is a Fiber Matched Channel (FMC) that matches the dimensions of the fiber. The length of this FMC isn’t very important. It is only there so the devices can be diced properly. A length of 1000 µm is there more than enough. The tapered waveguide waveguide than acts as a spot size converter between the FMC and the optical waveguide. The dimensions of the tapered waveguide are therefore on one side equal to the dimensions of the FMC and on the other side to the dimensions of the optical waveguide. With simulation-software of Kymata b.v. the ideal dimensions of the FMC (for which the field in the FMC matches the field in the HNA fiber) were determined. At a width of 1.4 µm the coupling loss between the fiber and FMC was polarization independent and lower than 0.25 dB (this is shown in figure 4 in which the overlap loss for different FMC widths is given). The
loss in this figure is for perfect alignment of the fiber to the waveguide. Misalignment of the waveguide was simulated and a coupling-loss-curve as in figure 5 was the result. The shape of the tapered waveguide after the FMC is an adiabatic shape with a minimum length of 500 µm (which was determined by BPM simulations), in figure 6 the radiation loss of such an adiabatic tapered waveguide is shown for different lengths. For the entire waveguide-structure all the dimensions are given in figure 7. Another parameter is the thickness of the SiO$_2$ bufferlayer under the SiON core. This thickness isn’t very critical. It only has to be thick enough so no light leaks into the silicon wafer. A thickness of 6 µm should be sufficient.

**Multiple fiber alignment**  
To be able to align multiple fibers simultaneously the fibers were placed in a V-groove array (figure 8). These V-grooves were fabricated by KOH etching of silicon wafers. A certain number of fibers are placed in the V-grooves after that a glass-plate is pushed on top and fibers are pushed in at the bottom of these grooves (schematically this looks as in figure 9). It is very important that the V-grooves aren’t too wide (maximum width = 153 µm)
because the top of the fiber should be lower than the top of the V-groove. This is because else the fiber won’t be pushed to the bottom of the V-groove. In this method the fiber is fixed at three points (see figure 10) and is therefore statically fixed. The V-grooves are typically etched with a bottom angle of 70.52°. Measuring the position of the fibers in these arrays is done by coupling light from one fiber into another (figure 11) and align the fibers such that maximum transmission is reached.

Array Measurements
To see what the position of the fibers in the V-groove array is (and than especially the position of the core of the fibers) the fibers in the two sets of fiber arrays were actively aligned as in figure 11 (fiber 1 is aligned to fiber 1 of the other array, fiber 2 to fiber 2 etc.). This was done for each fiber in the array and the displacement for which perfect alignment is reached (for each fiber separately) is compared to the position for perfect alignment of the outer fiber (fiber 1 in figure 11). The results of this measurement are given in figure 12 (here the position of fiber number 1 is set to zero. The vertical direction is in the direction of the arrow in figure 9. The horizontal direction is perpendicular to the V-groove)

According to the specifications of the fiber and the dimensions of the V-grooves the deviation of the core of the fiber in horizontal direction should be lower than \(0.93 \, \mu m\) and in vertical direction \(1.11 \, \mu m\). This is true for the points in figure 12. All these points are within range of the specifications of the fiber.

Conclusions

From the previous it became clear that a standard telecom fiber was coupled to an optical waveguide with a loss of less than 0.6 dB. The total loss of the coupling consists of the loss in the fiber splice, the loss in the coupling from HNA fiber to FMC and radiation loss from the tapered waveguide. This total loss is not more than 0.6 dB for perfect alignment. A coupling with a fiber array was realized in which the position of the core of the fibers was within the specification of the fiber. In the fiber array the maximum deviation of the core of the fiber was \(1.11 \, \mu m\), which results in an additional loss of 1.4 dB maximum.
References