**Modelling**

# Chapter Modelling and simulation

**%Introduction.tex**

In this Chapter the configurations of the experimental objects and corresponding technical detail will be at first introduced. Then it will be described the detail how the simulation models are approximated in CST MWS (CST Studio suite 2010) and the some performances of the simulations will also be illustrated in compare with the practical objects, such as working distance, minimum spot size, power distribution, etc .

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%%

## %Problem Deskription.tex

**\section{Project description}**

Coupling single-mode fibers to waveguides (Fiber-to-Chip coupling) by microlenses is a very common problem in integrated optics \cite{ integrated\_optics}, in wich waveguides locate on a substrate. By means of this technology the simple and reliable optical system with a small size become possible because a lensed fiber has a minized focal length. In this article the application of the lensed fiber-to-chip will be introduced and it coupling efficiency will be discussed.

Following Fig.\quad\ref{ fig:experiment\_object }is a schematic demonstration of fiber-to-chip coupling. At the one side there is a lensed tapered fiber as laser source and at another side at the working distance of the fiber there is a buried rib waveguide\cite{ integrated\_optics} as signal receiver. The purpose of this works is to find a way to gain optimized coupling efficiency through the simulations in CST MWS, which is a electromagnetic simulator basically with the implementation of the Finite Integration Technique (FIT)\cite{ cst\_help\_siulation\_method}.

\begin{figure}[!ht]

\includegraphics[width=.7\textwidth]{bilder/experiment\_object}

\caption{Fiber-to-Chip Coupling}

\label{fig:experiment\_object}

\end{figure}

\begin{figure}[!ht]

\centering

\subfigure[Picture of a real Single mode lensed fiber\cite{nanoscal\_tapered\_fiber}.]{

\includegraphics[width=0.3\textwidth]{bilder/single\_mode\_lensed\_fibber}

\label{fig:single\_mode\_lensed\_fiber}

}

\hfill

\subfigure[Schema of a tapered lensed fiber\cite{nanoscal\_tapered\_fiber}.]{

\includegraphics[width=0.6\textwidth]{bilder/tapered\_lensed\_fiber}

\label{fig:tapered\_lensed\_fiber}

}

\label{fig:TLFs}

\caption{NANOICS Tapered and Lensed Fibers}

\end{figure}

In this article the the tapered lensed fiber from NANONICS\cite{nanoscal\_tapered\_fiber} will be used. Fig.\quad\ref{fig:single\_mode\_lensed\_fiber} is the real image of the fiber and Fig.\quad\ref{fig:tapered\_lensed\_fiber} indicate its schema. In Tab.\quad\ref{tab:technical parameters\_lensed\_fiber} are listed part of technical parameters, which refer later to the modeling. Additionally the real woking frequence is $\lambda=1064$nm and working distance but $4\mu$m.

\begin{table}

\caption{Technical parameters about tapered lensed fiber.\cite{nanoscal\_tapered\_fiber}}

\begin{tabular}{c|c|c}

\hline

\multicolumn{2}{c|}{\textbf{Parameter}}&\textbf{Specification(Single-Mode)}\\

\hline

\multirow{3}{\*}{\parbox[t]{0.25\textwidth}{Spot Size of Aspheric and Convex Lenses($1/e^2$)}}&\multirow{2}{\*}{Minum}&$1.7\mu$m($\lambda=1.5\mu$m)\\

& &$0.6\mu$m($\lambda=0.6\mu$m)\\

&Maxium &$6.0\mu$m($\lambda=1.5\mu$m)\\

\hline

\multirow{2}{\*}{Spot Size Tolerance}&\parbox[t]{0.25\textwidth}{Without near-field characterization} &$\pm 0.5\mu$m\\

&\parbox[t]{0.25\textwidth}{With near-field characterization} &$\pm 0.25\mu$m\\

\hline

\multirow{2}{\*}{Working Distance} &Minimum &$5\mu$ m($\lambda=1.5\mu$m)\\

& Maximum &$50\mu$ m($\lambda=1.5\mu$m)\\

\hline

\end {tabular}

\label{tab:technical parameters\_lensed\_fiber}

\end{table}

\begin{figure}

\centering

\subfigure[Schema of a real waveguide.]{

\includegraphics[width=0.4\textwidth]{bilder/orignial\_waveguide}

\label{fig:orignial\_waveguide}

}

\hfill

\subfigure[Schema of a approxmate waveguide.]{

\includegraphics[width=0.4\textwidth]{bilder/approxmate\_waveguide}

\label{fig:approxmate\_waveguide}

}

\caption{Introduction of photonic waveguide}

\label{fig:photonic\_waveguide}

\end{figure}

The practical waveguide Fig.\quad\ref{fig:orignial\_waveguide} is a trapezoid guide on a semiconductor. But the angles $\theta$ of this guide approximate to $90^{o}$ and is not easy to measure because of its micro-size. Thus a simplified guide model Fig.\ref{fig:approxmate\_waveguide} will be used in this article. And the detailed technical properties of the photonic waveguide are given:

\begin{itemize}

\item working frequence $\lambda=1064 \mu m$

\item guide :LiNbO$\_{3}$ with $n1=2.516, w\approx 1\mu m, h\approx 0.5 \mu$m

\item substratum: SiO$\_{2}$ with $n2=1.544 $

\end{itemize}

## \section{Modelling}

For an economic simulation there is no need to create exactly identical models. Sometimes only parts of the specifics are requested. In this section the modeling process will be discussed.

### \subsection{Modeling the Lensed Fiber}

%fiber\_modeling.tex

First agenda is to determine the Tapered and Lensed Fiber(TLF) model. Because of the heave computing cost creating a full size fiber is not economical. Therefore only the end of the fiber, which provides approximately the equal technical properties, will be modeled in this works. In \cite{TLF\_analysis} \cite{TLF\_mode\_transforming} two type of the TLF configuration are mentioned.

\begin{figure}[!ht]

\centering

\subfigure[Tapered cladding TLF.]{

\includegraphics[width=0.4\textwidth]{bilder/lense\_fiber\_01}

\label{fig:lense\_fiber\_01}

}

\hfill

\subfigure[Tapered core TLF.]{

\includegraphics[width=0.4\textwidth]{bilder/lense\_fiber\_02}

\label{fig:lense\_fiber\_02}

}

\label{fig:two\_TLF}

\caption{Two types of Tapered and Lensed Fibers}

\end{figure}

The tapered cladding TLF Fig.\quad\ref{fig:lense\_fiber\_01} shows that its cladding diameter decreases along the beam propagation direction (z-axis) and its core diameter is a constant. For the tapered core TLF Fig.\quad\ref{fig:lense\_fiber\_02} its cladding diameter and core diameter both decrease along the axis. In \cite{TLF\_mode\_transforming} the Authour tried to develop methods to estimate the performance of both type of TLF. His results show that the performance of the first type of TLF agrees well with the estimation and that of the second type is unpredictable. In this section two TLF models from each type are created and their performances are tested in CST MWS.

First of all, determination the lens of both types is primary. For simplification, a hemispherical lens is assumed at the end of the fiber. Considering the working distance of the practical TLF, the lens configuration can be estimated through the lens theory. After estimations and some simulations one configuration of the lens is carefully selected Tab.\quad\ref{tab:model\_fiber\_configuration}.

\begin{table}

\caption{The Configurations of the TLF Models}

\centering

\begin{tabular}{ccc}

\hline

&Tapered Cladding&Tapered Core\\

\hline

R($\mu$m) & $6$ &$6$ \\

n$\_{core}$&$1.68$&$1.68$\\

n$\_{cladding}$&$1.66$&$1.66$\\

D$\_{clad}$($\mu$m) & $17$ & $17$\\

D$\_{core}$($\mu$m) & $10$ & $17$\\

D$\_{tip}$ ($\mu$m) & -- & $10$\\

\hline

\end{tabular}

\label{tab:model\_fiber\_configuration}

\end{table}

From Fig.\quad\ref{fig:lens\_spot} the beam propagation is demonstrated base on lens theory. As is in previous chapter described, the minimum spot located not exactly at the focal length. By using the location of PP and that of MP the MS can be estimated. are the theoretical beam propagation of the lense model. The theoretical distance from lens end to PP is $8.82 \mu m$ and the distance from lens end to MP is $2.74 \mu m$. Backword $3/4$ LAM form PP, the MS is founded at about $4.26 \mu m$far from lens end.

\begin{figure}

\centering

\subfigure[complete Beam Propogation from lense.]{

\includegraphics[width=0.4\textwidth]{bilder/cal\_min\_spot}

\label{fig:lense\_cal\_spot1}

}

%\hfill

%\subfigure[half Beam Propogation from lense and calculating the minimue spot.]{

%\includegraphics[width=0.4\textwidth]{bilder/lens\_cal\_spot\_168}

%\label{fig:lense\_cal\_spot2}

}

\label{fig:lens\_spot}

\caption{calculating minimus spot size by lense theory.}

\end{figure}

Implement this configuration for both types of TLF models in CST. Through simulations, E-Field demonstrations in the xz-plane of both type of TLFs can be drown as Fig.\quad\ref{ fig:Tapered\_cladding\_efield } and Fig.\quad\ref{ fig:Tapered\_core\_efield } .

\begin{figure}[!ht]

\subfigure[E-Field demonstration of Tapered cladding TLF]{

\includegraphics[width=0.4 \textwidth]{bilder/cst\_lensed\_fiber\_equ\_efield}

\label{fig:Tapered\_cladding\_efield}

}

\end{figure}

\begin{figure}[!ht]

\subfigure[E-Field demonstration of Tapered core TLF]{

\includegraphics[width=0.4 \textwidth]{bilder/cst\_lensed\_fiber\_efield}

\label{fig:Tapered\_core\_efield}

}

\caption{E Field demonstration}

\end{figure}

Load the its beam propagation detail into \textbf{Matlab} workspace and check the 2D and 3D beam power distribution in different distance. Fig.(\ref{fig:2d\_spot\_sub1}-\ref{fig:2d\_spot\_sub8}) and Fig.(\ref{fig:3d\_spot\_sub1}-\ref{fig:3d\_spot\_sub8}) respectively.%2D and 3D

\begin{figure}[!ht]

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\subfigure[2D Beam Power at distance $1\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_1um}

\label{fig:2d\_spot\_sub1}%

}

\subfigure[2D Beam Power at distance $2\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_2um}

\label{fig:2d\_spot\_sub2}

}

\subfigure[2D Beam Power at distance $3\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_3um}

\label{fig:2d\_spot\_sub3}

}

\subfigure[2D Beam Power at distance $4\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_4um}

\label{fig:2d\_spot\_sub4}

}

\subfigure[2D Beam Power at distance $5\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_5um}

\label{fig:2d\_spot\_sub5}

}

\subfigure[2D Beam Power at distance $6\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_6um}

\label{fig:2d\_spot\_sub6}

}

\subfigure[2D Beam Power at distance $7\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_7um}

\label{fig:2d\_spot\_sub7}

}

\subfigure[2D Beam Power at distance $8\mu m$]{

\includegraphics[width=0.29 \textwidth]{bilder/surface\_spot\_8um}

\label{fig:2d\_spot\_sub8}

}

\caption{2D Beam Spot }

\end{figure}

\begin{figure}[!ht]

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\subfigure[3D Beam Power at distance $1\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_1um}

\label{fig:3d\_spot\_sub1}%

}

\subfigure[3D Beam Power at distance $2\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_2um}

\label{fig:3d\_spot\_sub2}

}

\end{figure}

\begin{figure}[!ht]

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\subfigure[3D Beam Power at distance $3\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_3um}

\label{fig:3d\_spot\_sub3}

}

\subfigure[3D Beam Power at distance $4\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_4um}

\label{fig:3d\_spot\_sub4}

}

\end{figure}

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\subfigure[3D Beam Power at distance $5\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_5um}

\label{fig:3d\_spot\_sub5}

}

\subfigure[3D Beam Power at distance $6\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_6um}

\label{fig:3d\_spot\_sub6}

}

\end{figure}

\begin{figure}[!ht]

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\subfigure[3D Beam Power at distance $7\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_7um}

\label{fig:3d\_spot\_sub7}

}

\subfigure[3D Beam Power at distance $8\mu m$]{

\includegraphics[width=0.4 \textwidth]{bilder/surf\_spot\_8um}

\label{fig:3d\_spot\_sub8}

}

\caption{3D Beam Power }

\end{figure}

Draw Fig.\ref{fig:Tapered\_cladding\_spot\_curve}-\ref{fig:Tapered\_core\_spot\_curve} to illustrate the beam Spot size diameter along the longitude axis.

\begin{figure}[!ht]

\subfigure[Spot Size Curve of Tapered cladding TLF]{

\includegraphics[width=0.4 \textwidth]{bilder/flower\_hiber\_cladding}

\label{fig:Tapered\_cladding\_spot\_curve}

}

\hfill

\subfigure[Spot Size Curve of Tapered core TLF]{

\includegraphics[width=0.4 \textwidth]{bilder/flower\_hiber\_core}

\label{fig:Tapered\_core\_spot\_curve}

}

\caption{Curve of Spot size diameter}

\end{figure}

Fig.\ref{fig:Tapered\_cladding\_spot\_curve} and Fig.\ref{fig:Tapered\_core\_spot\_curve} shows the spot diameters of both configurrations along the propogation direction by using z-compent and absolute value of their power flow density. Here choose the curve from absolute value of their power flow density to determine the minimum spot. From Fig.\ref{fig:Tapered\_cladding\_spot\_curve} that the minimum spot size locate at about $4.1 \mu m$ from lense end and spot size equal about $1.5 \mu m$. While in Fig.\ref{fig:Tapered\_core\_spot\_curve} that the minimum spot size is found at $4.3 \mu m$ from lense end and spot size equal about $1.5 \mu m$. Thus it is concluded that two configuration has only a small difference. By rechecking the properties in Tab.\ref{tab:technical parameters\_lensed\_fiber} both TLF model are acceptable for the following development. In this article the Tapered core TLF will be used for further simulations.

### \subsection{Modeling the Fiber to Chip}

%fiber2chip\_modelings

As Fig\ref{fig:experiment\_object} put the waveguide model at the MS point of TLF. In this case the beam field at the propragation direction has changed.( (Fig.\ref{fig:coupling\_e\_field}) The simulation result in Fig.\ref{fig:orignial\_coupling\_efficiency} shows at the working frequence $282hz(\lambda=1064 nm)$ the coupling efficiency ($S\_{21}$) is about $488\%$.This result will act as the reference sample for the other simulations. From Fig.\ref{fig:power\_distribution} the power distribution along the waveguide can be observed.

\begin{figure}[!ht]

\centering

\includegraphics[width=0.5 \textwidth]{bilder/basic\_waveguide\_efield}

\label{fig:coupling\_e\_field}

\caption{E-Field demonstration by coupling.}

\end{figure}

\begin{figure}

\centering

\includegraphics[width=0.7\textwidth]{bilder/original\_coupling\_efficiency}

\caption{coupling efficiency in Frequency area.}

\label{fig:orignial\_coupling\_efficiency}

\end{figure}

\begin{figure}[!ht]

\centering

\includegraphics[width=0.7\textwidth]{bilder/power\_distribution}

\caption{power distribution along the waveguide.}

\label{fig:power\_distribution}

\end{figure}

