Design and modelling of optical microsystems - an approach to a user-friendly system integration technique

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ABSTRACT

Optical microsystems usually are of a hybrid nature. They consist of optical components. i.e.micro-optical and or integrated-optical ones, and additionally they include at least mechanical and packaging components. Therefore, a complete design process has to account for all relevant aspects – optical and thermomechanical simulation, packaging strategy, fabrication and test.

This complexity requires a general design strategy. The approach presented is based on the coupling of the specification and the design. In a specification- environment the selection of appropriate solutions for given applications is enabled. It includes selection strategies for componebts, ist fabrication, packaging and test methods. The design-environment is a simulation and modelling framework with software tools covering the whole design and optimisation process, including the data-exchange with the specification environment. Test examples for our design strategy are different realisations of fibre optical switches.

INTRODUCTION

The design process for optical systems generally starts on the basis of commercial elements. The high diversity of micro-optical components and systems requires the selection, assessment and structured information about applications, known realisations and the demands of the system integration. To develop specialised elements, additional information about materials and technologies is needed. Concerning the fabrication, packaging and measurement strategies should be known to the engineer as well as patents, standards, manufacturers, and suppliers.

In general, the design of single components is a today's standard task that is efficiently supported by various specialised software tools. However, optical microsystems usually consist of different components, e.g. laser diodes and coupling optics. This results in complex three-dimensional configurations and demands the coupling of several suitable optical and thermo-mechanical simulation tools. Additionally, packaging and assembling techniques must be included in the design process. Here, we present a general and efficient specification and simulation strategy suitable for the design and optimisation of optical microsystems. As an example we choose different types of fibre optical switches.

The main goal is to contribute to a time and cost-efficient design and fabrication process which is of increasing importance and which is addressed in some recent publications, too [1-3].

BASIC CONCEPT

Our design strategy is based on a specification-environment and a design-environment which are fed by underlying databases. The specification-environment enables the selection, assembly and assessment of an optical microsystem. Additionally, it provides structured information about applications and known realisations. The design-environment is a general simulation and modelling framework with several software tools covering the whole design and optimisation process.

The specification-environment (Fig. 1) is hierarchically structured. It is divided into several definition levels whereby the level set-up is dynamically read out of the database. On each level the user has to choose an item out of several alternatives given by the environment and may specify certain parameters which influence the following design steps. Items satisfying the current specifications can be identified on each level with an appropriate database structure. Unfulfilled specifications result in items which cannot be selected.

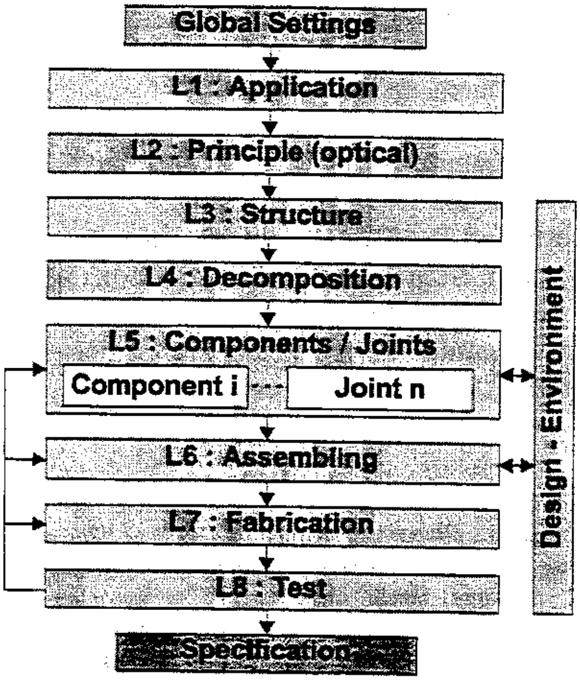

Figure 1. Specification Process

The environment assists the user in the design process by supplying additional information and context sensitive help. Starting the specification the user may set global preferences thus imposing general restrictions on the microsystem.

On level 1 the current application has to be selected, which may be chosen out of the fields information processing, sensor/measurement technology and imaging/ illumination. After that, the underlying functional principle of the optical micro-system must be determined (level 2). On level 3 the user can select one realisation from a list of possible configurations whereby a decomposition in components and assigned joints will be performed (level 4). After that, on level 5 the different components and joints have to be sequentially characterised. Functional and geometrical dependencies of the components and assigned joints are tested to guarantee compatibility during the definition process. Components may either be given by its data sheet (externally supplied parts) or must be fully defined through user input (self manufactured parts). Similar definition mechanisms are applied for joints. On level 6 the sequence of assembly has to be determined by user interaction. The detailed fabrication process and the selection of appropriate production techniques are the contents of level 7. Finally, test strategies for subsystems and the complete microsystem can be chosen (level 8). During the design process mutually excluding specifications can be made which lead to non realisable systems. In such cases the resulting problems may be stepwise resolved. If this method remains unsuccessful an extension of the database is required. For this reason an update assistant has been developed. Necessarily, an optimisation must be performed for every system design until the relevant specifications are met. For this reason, a transition from the specification-environment to the design-environment is possible in order to simulate the current system or parts of it. The results of such calculations are used in the further design process.

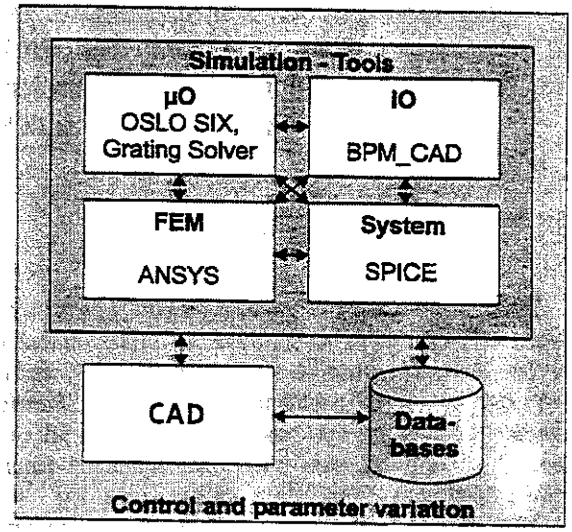

Figure 2. Design-Environment

The structure of the design-environment is presented in Fig. 2. It is a framework which allows the design and optimisation of a concrete configuration by providing all required tools. Interfaces between the design tools for integrated optics and refractive and diffractive micro-optics have to be used for more complex systems as well as interfaces to pass on information about geometry, mechanical and thermal loads to corresponding Finite Element and CAD tools.

Macromodelling techniques with analogue simulators are used to describe more complex interactions between temperature distributions, light waves, and mechanical deformations. In that way, a rapid modelling of the whole system is possible. The framework has access to the databases for getting template system geometries, simulation macros, geometry definitions and material properties. In order to allow the optimisation and tolerancing of a basic layout, a scaleable geometry model with parametric data is required. Generated by the specification-environment, a basic geometry and several specifications are the input parameters to this design-environment. An optimised geometry will be returned.

Moreover, the specifications made by the user may be altered.

EXAMPLES

The considered examples are different realisations of fibre optical switches by which light emitted by a laser diode can be coupled into two separate monomode fibres. Fig. 3 shows a micro-optical realisation including a microprism as the beam steering element, which is driven by a piezoelectric actuator. If switching times in the range of 1 ms and the voltage supply to the piezo actuator are compatible to the given specifications, this realization can be selected for further actions.

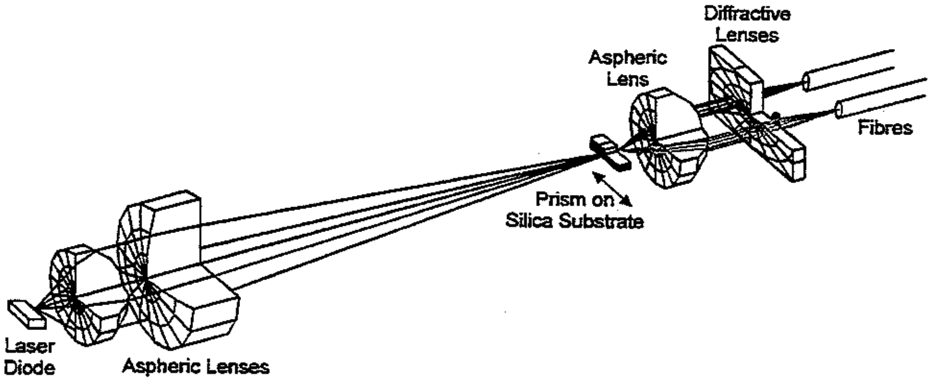

Figure 3: Micro-optical fibre switch

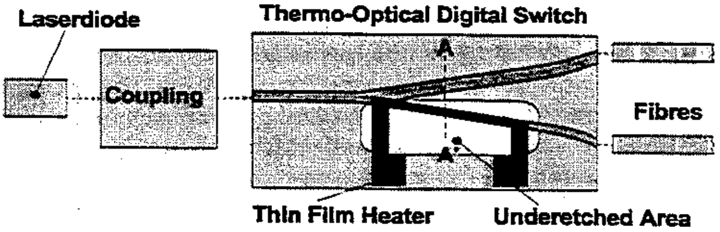

Figure 4a. Integrated optical fibre switch

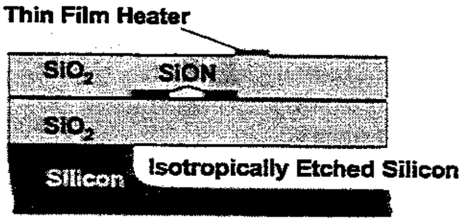

Figure 4b. Underetched waveguide structure

In our example the optical design can be done completely within the OSLO™ program. If vignetting effects at the prism edges have to be considered, a design tool which includes the capability to model diffraction has to be used. In this case an interface from ray tracing to a wave propagation software and vice versa is necessary. This interface is used similarily, when the coupling from or to waveguides with arbitrary field profiles has to be considered. Then, the propagation in the waveguides, i.e. in the integrated optical components, is modelled with BPM software (e.g. BPM_CAD™).

From the optimisation and tolerancing of the configuration within the capabilities of OSLO™, the parameter(s) introducing the most rigid requirements for the processing and packaging can be recognised. After the generation of an adapted submount structure thermal loads corresponding to given specifications can be applied to the geometry under consideration using ANSYS™.

A different fibre optical switch is shown in Fig. 4. Here, the switching is realised by a thermally induced refractive index change. The integrated optical 1x2 TODS (thermo-optical digital switch) [4] is fabricated by plasma deposition of SiO_2 / SiON / SiO_2 waveguide layers and RIE delineation. The switching power is strongly reduced by silica and silicon micromachining.

The main optical design is done by BPM. The thermally induced refractive index change is modelled within ANSYS™. Thereby, the optimisation with respect to switching power is possible. For a complete design the laser diode, the coupling optic and the output fibres have to be included. This requires a modelling section within OSLO™ and the use of the appropriate interface routines again.

The concept of another fibre optical switch shown in Fig. 5 is based on two binary single order gratings arranged reverse with a thin gap. If the piezoelectric actuator shifts one grating sideways, the light is switched between the 0th and 1st order. Both gratings and the gap can be simulated and optimised together with their substrates and anti-reflection coatings as a complete system by GSOLVER™.

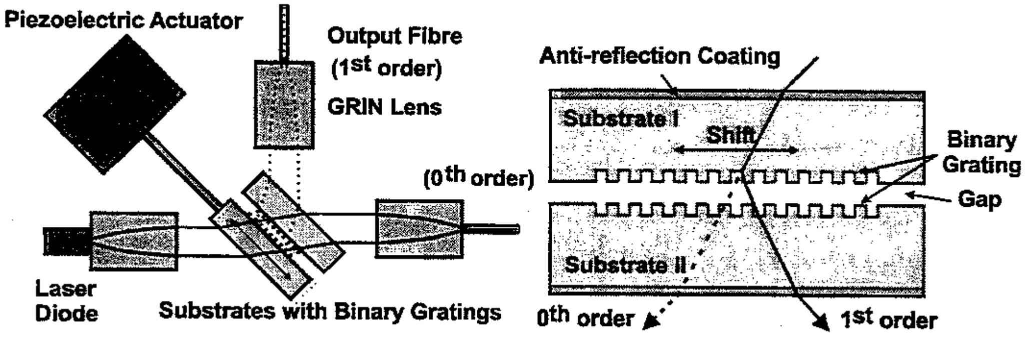

Figure 5: Micro-optical fibre switch based on two single order gratings

An interface tool allows its integration in OSLO™. The collimation and focusing to the fibres are calculated within OSLO™, too. The thermal analysis with ANSYS™ yields the thermally induced wavelength change of the laser diode that affects the diffraction efficiency and angle. The required precision for placement and dislocation imposes great demands on the packaging and assembling techniques as well as the test strategies.

From the database detailed information is available concerning the technological efforts necessary for fabricating the microsystems. Production, packaging, and test may be characterised within the specification-environment. Moreover, information to standard technologies is supplied.

SYSTEM MODELLING

To show the approach used here for system modelling we refer to the example of the micro-optical fibre switch as given by Fig. 3. After choosing suitable, commercially available components from the database and optionally adding and/or updating user defined components the basic layout of the whole optical microsystem is generated within the specification-environment.

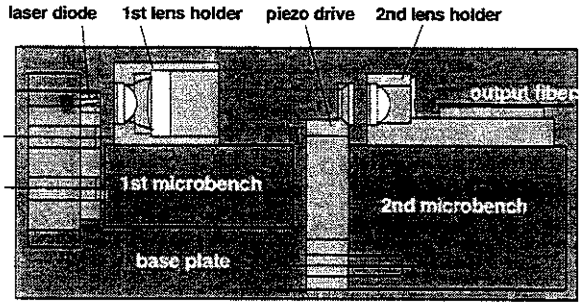

Figure 5. System assembly of the fibre switch

Packaging aspects are also taken into account by compatibility checks made between the component properties and the technological parameters of the required packaging processes. For example the component surface and the temperature stability are important parameters for processes like soldering or gluing.

The result of the system specification may be a design like that in Fig. 5. As a system carrier we use a base plate made of brass. The laser diode on its submount is soldered onto a subcarrier which is affixed to the base plate within an adjustment grove. The lens holder of the first lens doublet is glued onto a precision milled microbench. For shifting the microprism perpendicular to the optical axis (see also Fig. 3), a piezo driver is used which is mounted on a second microbench. The lens holder 2 with a refractive and a diffractive lens as well as the V-groove Si- carrier for the two output fibres are mounted on the second microbench, too.

The functional performance of the whole optical microsystem, which is the essential part of the output of the design-environment, is affected at last by deviations of the optical components from their optimal positions in the light path. The reasons for such displacements could be

1. fabrication tolerances of the components,
2. tolerances within the system geometry due to assembling, and
3. thermo-mechanically caused shifts of the components.

The influence of these deviations was investigated for this micro-optical fibre switch within the optical design tool OSLO™ by using a tolerancing procedure. The result is a coefficient set describing the system behaviour in dependence on the shift of the optical components, i.e. it is a worst case consideration.

Transferring the coefficient model to an analogue simulator like PSpice™, the behaviour of the optical subsystem can be described by means of the coefficients. When the individual optical components are combined with the others, i.e. the carrier, the subcarrier, the lens holders, the piezo driven switch, and the laser diode, additional physical aspects influencing the systems performance have to be taken into account. These include mechanical, thermo-mechanical, optoelectronical or even electrical effects, which can be efficiently incorporated into the design within an analogue macro model of the system, thus reducing and/or avoiding multiple, numerically intensive calculations.

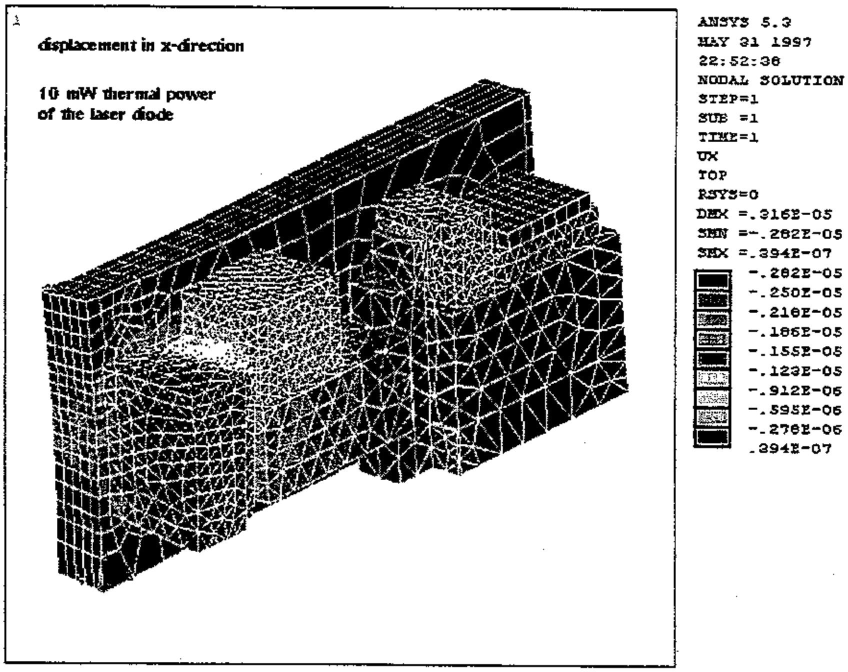

Figure 7. Thermo-mechanic simulation of the micro-optical fibre switch, displacement in x-direction is shown

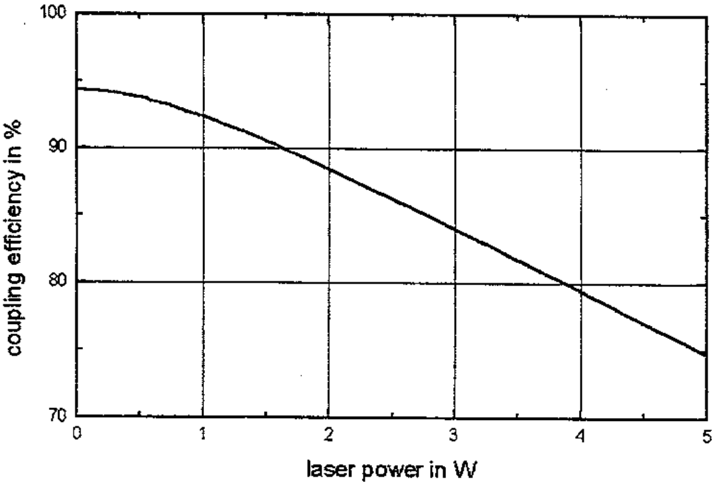

Figure 8. Optical transmission efficiency of the micro-optical fibre switch
in dependence on the thermal power of the laser diode

In the case of the micro-optical system investigated here the thermal power of the laser diode induces thermo-mechanical shifts of the optical components. This results in a reduction of the optical transmission efficiency of the whole system. Choosing a laser diode with 10 mW thermal power, the result is a deformation of the microsystem assembly as shown in Fig. 7. The dislocation of the optical surfaces (x-, y-, z-displacement, and rotation) is transferred via an output file to the analogue simulator. According to the coefficient model of the optical components the thermal induced displacements influence the transmission efficiency directly. The result of this macromodelling approach is a description of optical transmission efficiency of the whole system in dependence on the thermal power of the laser diode (Fig. 8). Our example shows that a thermal power of 1,5 W would be a limit for the chosen system set-up (90 % of the optimum efficiency, which is reached when temperature effects are neglected). Although this power-limit is reasonable high, it demonstrates that thermo-mechanic effects can considerably affect the system performance and thus must be taken into account during the design process.

Additional to the OSLO™ tolerancing scheme explained above the re-import of the geometry altered due to the temperature into OSLO™ allows for a check whether a fault compensation due to the combination of the shifts of the different system elements can be reached or not. The model presented above incorporates the mutual dependence between thermo-mechanical and optical effects.

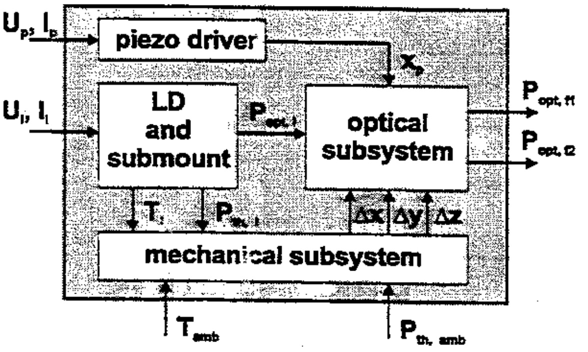

Figure 9: Macromodel for the micro-optical fibre switch

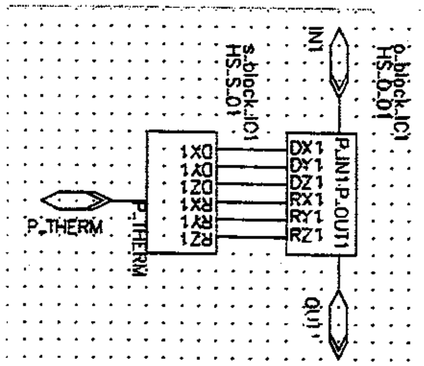

Figure 10: Thermomechanical effects in the PSpice model

A more versatile macromodel allows a complete characterisation of the microsystem by means of its input and output parameters (Fig. 9). As input parameters we have here the driver current and voltage for the piezo and the laser diode. Moreover, the ambient temperature and an additional cooling may be regarded. The output parameter is the optical power in the single mode fibres. Fig.10 shows the building block for a single optical component in the PSpice model, which accounts for the thermomechanical influence onto the output optical power via the components displacements and rotations.

The simulations described in this section are used to determine the inner quantities of the model. In general, a combination of a white box and a black box model is used. Known physical dependencies can be modelled by mathematical formulas (white box model), for unknown dependencies parametric relationships taken from simulations and measurements are necessary (black box model).

SUMMARY AND CONCLUSION

A general strategy suitable for the design of optical microsystems has been presented. Complementary to optical and functional dependencies thermo-mechanical properties are taken into account. The design is supported by a database tool which guides the user during the definition process and supplies all information needed for developing a basic system layout. With the help of coupled simulation tools this system layout may be altered and optimised. A macromodel allows an simplified parametric description of the whole system.

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