Numerical Simulations to Predict the Functionality of Optical Devices

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Abstract

At the Institute of Microstructures in the Research Center of Karlsruhe (FZK) optical devices are developed in microstructure technologies [1]. Because of the miniaturized dimensions of the optical components, a very high accuracy must be guaranteed by the fabrication process. Furthermore, the exactly fabricated measures must be kept during the real application process.

The knowledge about the qualitative and quantitative deformations, resulting from the real surrounding parameters (pressure, heat loads) in the application is essential. The question is, are the expected deformations large enough to make device malfunctioning, or are they small enough, to keep the desired functionality within the given tolerances.

These informations concerning the deformed device solids can and have to be generated by numerical simulations before the very expensive fabrication process. The results of the simulations influence the design and the construction of the optical devices.

Keywords: microstructures, FEM, structure analysis, heat generation, structural behavior

1 Introduction

At the research center of Karlsruhe, the LIGA (X-ray lithography, electroforming, plastic molding) process is established, to produce microstructures with any 2-dimensional shape with aspect ratio up to 100. One very interesting type of structures are microoptical benches, especially a heterodyne receiver. This is a coherent lightwave system, which correlates a received signal coherently with another optical signal, generated by a local laser diode [2].

In this paper, FEM models and simulation results concerning the heat dependent deformation are presented using an example of heterodyne receiver (see figure 1) and its components. The functionality of the different components is only guaranteed, if the fabrication-related tolerances and the partial influences of the surroundings on the geometrical structure are considered. The geometric measures are directly correlated with the optical features of the optical device.

This paper concentrates efforts on

(1) embedding the optical devices into temperature dependent surroundings,

(2) heat transfer between optical components and surroundings,

(3) heat generation of an active laser diode within an optical device.

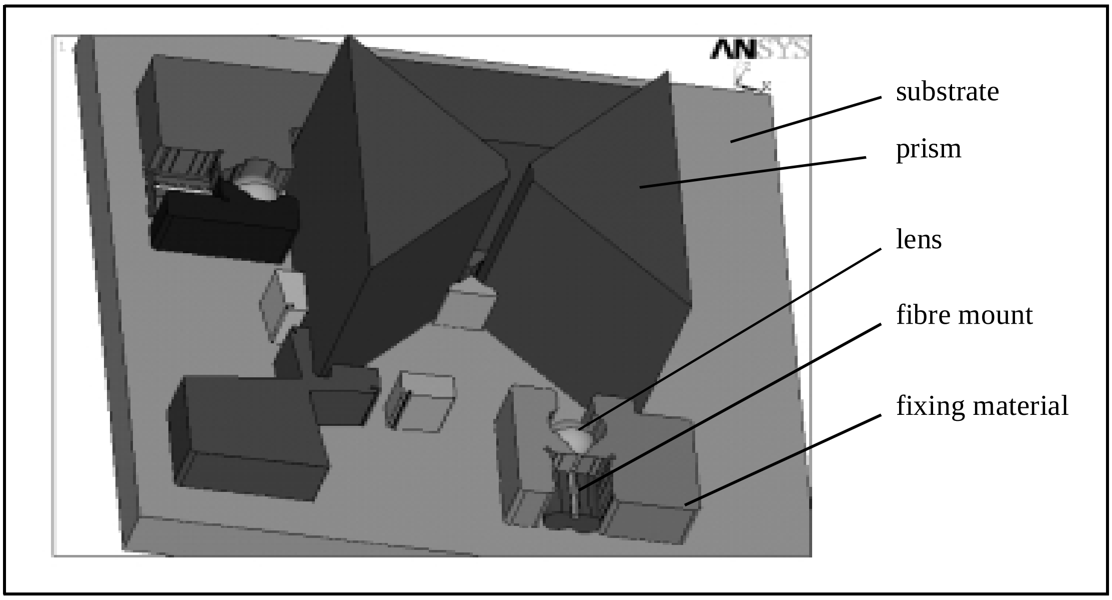

Figure 1: Solid model of heterodyne receiver, one prism faded out

The results of the coupled field analysis methods are demonstrated, which are the base for decisions, whether the aimed functionality of the optical device can be guaranteed or not.

2 Problem Analysis and Description

The problem which has to be solved from view of the optical functionality is a correct superposition of the signals at the position of the photodetector.
Concerning the microfabrication process of the different optical components (lense, laser diode, prism, substrate, photodetector) there are used different materials, having different structural behavior under thermal loads and affect directly the beam propagation within the optical system. In physical context, structural and thermodynamical behavior is regarded under different aspects (see figure 2).

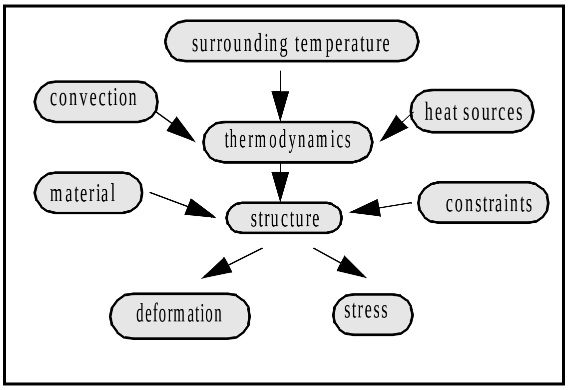

Figure 2: Physical context and logical interfaces

Thermal loads are subdivided into two categories.

(1) The application of the coupled material mixed structure in a temperature dependent environment leads to necessity to consider convection between structural material and surrounding air.

(2) The laser diode is an active heat generator in a very small surrounding of the other optical components. The heat transfer from the doped layer to the Ni-base and to the other components must be regarded.

In this work, the coupled system (laser diode, sphericl lenses and a fibre mount), fabricated on a substrate is modeled in request of FEM-simulations. The different modeled solid components include different material behavior. Especially the material junctions have to be considered because there are expected high stress components based on different temperature expansion coefficients.

For the simulation model special interesting components of the complete heterodyne receiver are selected and the simulation process relates on the material junctioned subsystem.

The regarded components are a ceramic substrate (AL_2O_3) as platform for all optical devices, a spheric lens (glass), a Ni-block fixed on substrate with a small doped layer in a very small InP-block on the top of the Ni-block and a fibre mount (PMMA) inclusive a fibre to couple in the light waves (see figure 3).

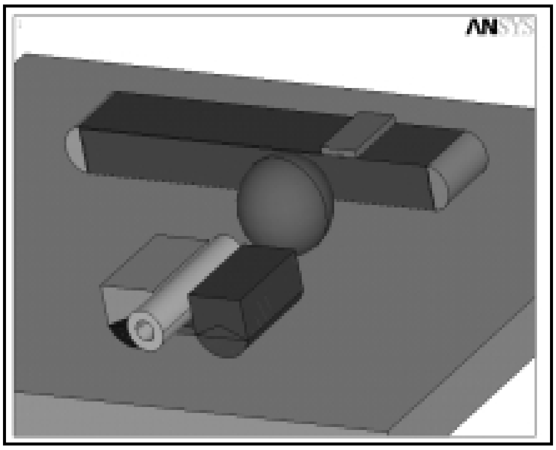

Figure 3: Selected optical subsystem

3 FEM Simulation of thermodynamical and structural behavior

Concerning the different material dependent components a solid based model has been used with mixed mesh algorithms (mapped meshing and also free meshing with tetrahedrons) (see figure 4).

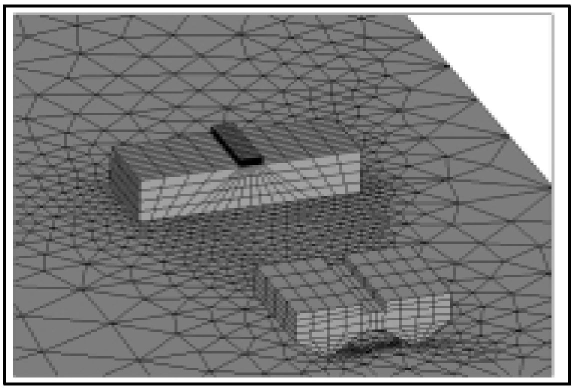

Figure 4: Solid meshing (mapped and free)

Material junctions are simulated as common net nodes regarding both materials. Common nodes for example belonging to the fibre mount and the substrate are shown in the figure 5.

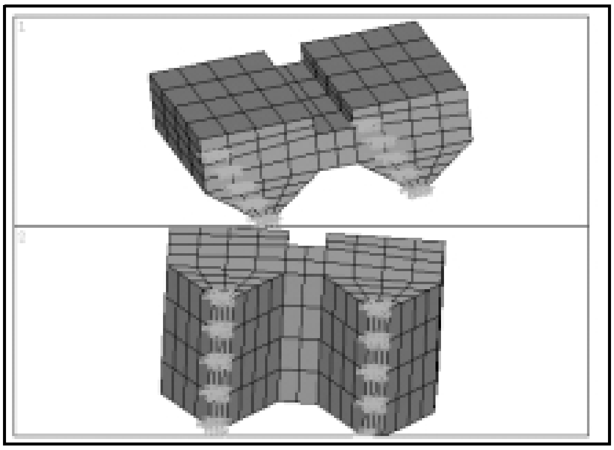

Figure 5: Fixing conditions at the bottom of fibre mount

Within the coupled field analysis the first step is a special *thermal analysis*:
The temperature field is calculated dependent on the material parameters, geometric parameters, the convection between the components and the air and the heat source (laser diode).
Input parameters for this analysis are *conduction, convection and heat radiation*.
The next step is the structure analysis. Dependent on the given geometry, the material parameters and the calculated temperature field the displacement of all interesting nodes have to be calculated. Input parameters for the structural analysis are the *elastic modulus, Poisson ratio and expansion coefficients*.

In figure 6 the coupled procedure of analysis is shown. The complete model (geometry, netsizing) was parametrized, so that a new configuration of the optical components with other measures can be modeled in an easy manner.

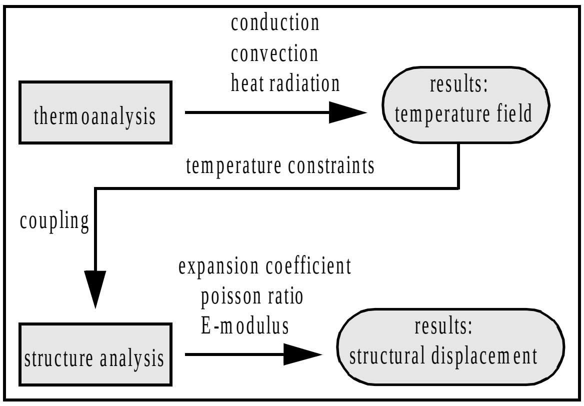

Figure 6: Coupled field analysis

4 Results of the Coupled Field Analysis

While cooling the substrate from the bottom, a temperature distribution is given while active heat generation in the doped layer (see figure 7 and figure 8).

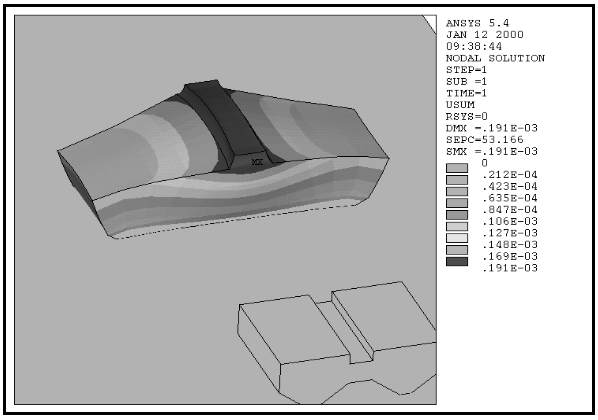

Figure 7: Temperature field (based on heat generation)

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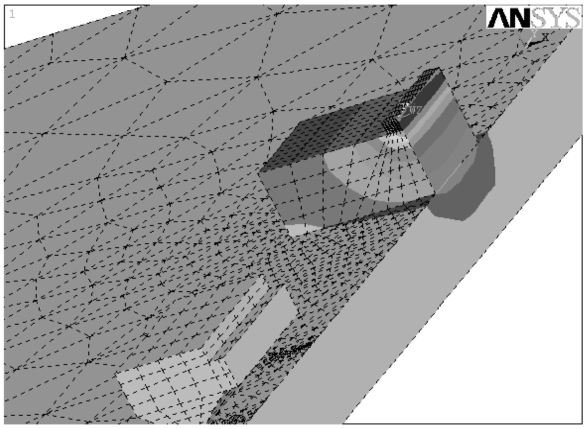

Figure 8: Cross section in temperature field for the meshed solid

The influence of the heat generation in the laser diode to the adjacent components, mounted on the substrate, are minimal and can be neglected. So no significant solid displacements are expected for the other components. Only small displacements based on surrounding homogeneous temperature is regarded. Results are shown in figure 9 for the fibre mount, in figure 10 for the prism subsystem and in figure 11 for the lens system including fixing components.

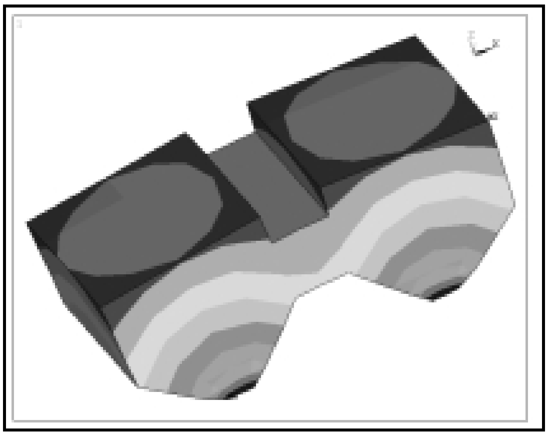

Figure 9: Displacement of fibre mount

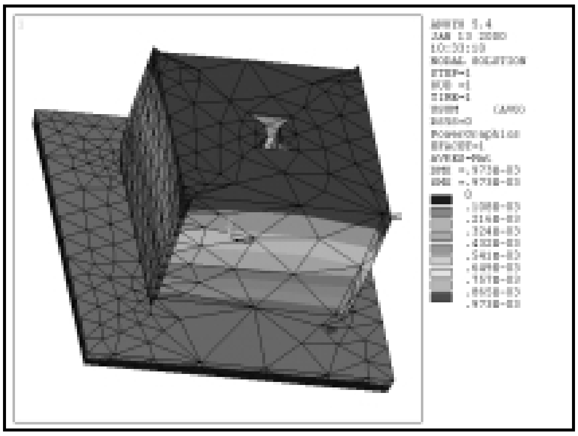

Figure 10: Node-Displacement of prism subsystem

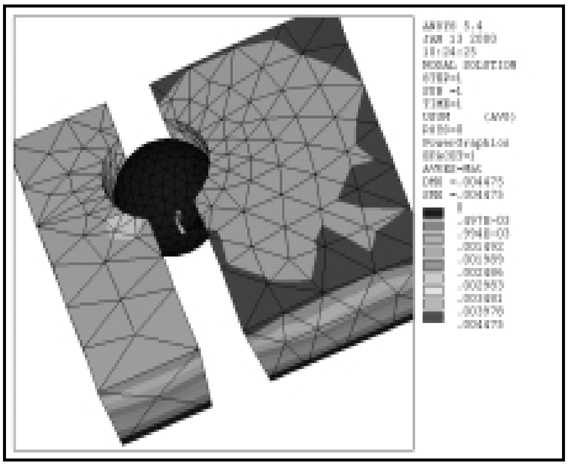

Figure 11: Displacements for lens and fixing components

But the induced distortion and strain and stress values at the material interfaces leads to a tilt of the area of the laser front, which is no longer a plane (see figure 12). That means, the light beams, going out in orthogonal direction to the plane, are deflected. So, the light beam input at location of fibre mount is not 100% of generated energy in the laser diode. The amount depends on the distance between the fibre in the fibre mount and the laser diode, the heat generation rates and the material interface between the Ni-block an the InP-layer as laser diode. Furthermore, the original plane is tilted because of stress moments at the junction between the InP-block and the Ni-block (different temperature expansion coefficients).

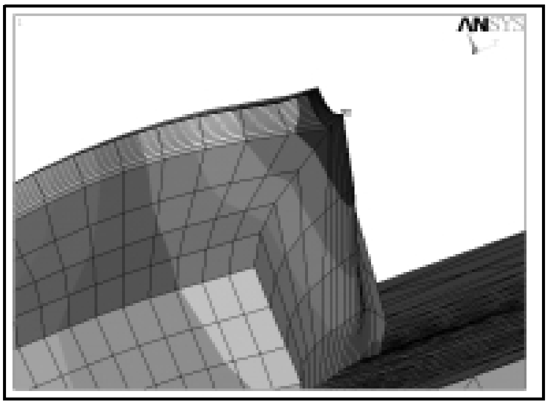

Figure 12: Tilt of the laser front, based on active heat generation

5 Conclusion

A conclusion of the simulated results with the nonlinear displacement at the material junctions is the idea of spending material kits between the Ni-block and the doped laser diode. Also, an answer of designed measures is given, dependent on the question, how much intensity of light must be detected at the photodetector.
All simulations are performed with the commercial FEM Tool ANSYS 5.4, running on a SUN-workstation under SOLARIS.

6 References

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