

Fabian Utermöhlen

Modeling of MEMS Microbolometers

A Physics-Based Scalable Compact Model

This thesis describes the development of a MEMS microbolometer compact model which includes the full signal path from thermal infrared (IR) emission by an object to the electrical input of a read-out circuit.

In the optical module of the compact model, the spectral radiation emitted by an object, the transmission losses due to atmospheric interaction and optical systems (e.g. lenses), and, finally, the absorption in a microbolometer pixel are calculated. The absorption is predicted using the transfer-matrix method based on wavelength dependent complex refractive index models.

Since the pn-junction diode is used as temperature sensitive device in this thesis, a theoretical derivation of its temperature sensitivity is provided. Based on that, an optimized doping profile design with corresponding process parameters is developed in order to increase the sensitivity while suppressing electrical noise. It is demonstrated that a low current density and a current flow far away from the defective surface significantly improve both parameters.

The signal transformation from absorbed IR radiation to a temperature increase of the microbolometer pixel is modeled by a dynamic electrothermal network. The network consists of four topologies which include an increasing number of heat conduction mechanisms, temperature dependencies of the material parameters and absorption mechanisms with increased complexity level. For the calculation of the network elements, temperature dependent thermal conductivities and specific heat models for commonly used solid materials as well as pressure dependent models for the thermal conduction in gas mixtures are provided. These models are validated by thermal impedance measurements of manufactured microbolometer pixels and by static and dynamic material parameter extractions with dedicated test structures and algorithms.

Unfortunately, thermally favorable pixel designs are often hampered by a decreased mechanical robustness. Therefore, a mechanical analytical modeling approach is presented, which approximates the pixel structures as spring-mass-systems and allows for a calculation of the pixels' eigenfrequencies without requiring time-consuming FEM simulations. All relevant modeling parameters can be derived from Laser-Doppler vibrometer eigenfrequency measurements of specific test structures.

Due to the limited shrinking potential of multiple pn-junction diodes on a microbolometer pixel, connected in series for an increased signal, two alternative temperature sensing concepts with corresponding read-out algorithms are developed. These novel concepts allow a fully CMOS compatible manufacturing process and show a high miniaturization potential and a straightforward integration on the presented microbolometer pixel designs.

Finally, all sub-models are connected within a common module in order to calculate the full signal path and to determine important sensor figures of merit like the noise equivalent temperature difference (NETD), i.e. the object temperature resolution of the microbolometer