A matrix formalism for the simulation of pyroelectric sensors

D. Lienhard and B. Ploss[a)]
Institut für Angewandte Physik, Universität Karlsruhe, Kaiserstrasse 12, D–76128 Karlsruhe, Germany

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A pyroelectric sensor generates an electrical output signal as the response to incident radiation. Aside from the pyroelectric effect, the absorption of radiation and the heat propagation are essential for the signal generation. Therefore, the simulation of the sensor signal must cover the optical, thermal, and electrical processes. For the optical and thermal modelling of pyroelectric multilayer structures, a matrix formalism is given, which handles the propagation of electromagnetic and thermal waves in a similar way. Starting with the dielectric properties of the materials involved, the local absorption density is determined. With the thermal properties and the polarization distribution the temperature profile and the pyroelectric current are obtained. Implemented in a computer program, sensor signals of arbitrary multilayer sensors can be calculated. The method is applied to the modelling of integrated pyroelectric sensors.© *1995 American Institute of Physics.*

I. INTRODUCTION

The research on infrared sensors has been stimulated in recent years by a wide variety of applications. Examples are spectrometers for the gas analysis, the automatic supervision of fabrication processes, especially in the chemical industry, or thermal imaging for fire detection and automatic fire fighting. In particular, the effort is focussed on integrated sensors and integrated sensor arrays. Several methods for the integration of pyroelectric materials on a silicon chip containing amplifiers and multiplexers are reported in the literature.[1–3]

A pyroelectric sensor is a system, which generates an electric signal as the response on incident infrared radiation. It consists of a pyroelectric element, covered with metal electrodes, a structure for the absorption of incident radiation and a substrate at the back of the sensor.

Various physical processes take place in the sensor for the generation of the output signal and are essential for the sensor performance. The first process is the propagation of the incident electromagnetic wave in the sensor structure. Determined by the optical properties of the sensor components results the spatial distribution of the electric field amplitude and by that the absorption density in the device. The distribution of absorbed power forms the boundary condition for the generation of thermal waves in the sensor. The propagation of the thermal waves leads to the spatial profile of the temperature amplitude, which in combination with the pyroelectric material properties determines the pyroelectric output signal.

An integrated pyroelectric sensor with good performance cannot be constructed by assembling it of functionally separated modules, each one optimized for a specific task. In a well designed sensor system these tasks are mixed, e.g., the pyroelectric layer is also acting as an essential component of the absorber structure.[4] Therefore, tools for the sensor simulation are required, which cover the optical, thermal and electric properties.

Integrated pyroelectric infrared sensors are multilayer structures of various materials, including an absorber structure, the pyroelectric film, electric contacts, the silicon chip, and additional layers to improve the sensor performance.

Matrix formalisms are very appropriate to calculate the propagation of waves in layer structures. Reported in the literature are, for example, matrix formalisms for the calculation of optical reflection and transmission coefficients[6] and for the simulation of photoacoustic spectra of multilayer structures.[7] Here we present a formalism for the simulation of pyroelectric sensor response, which is based on matrix representations for electromagnetic and thermal waves.

II. THEORY

We consider the case that an electromagnetic wave with the (complex) amplitude E, the complex wave number k and the circular frequency ω:

$$E(z,t)=Ee^{ikz-i\omega t} \tag{1}$$

is incident on the surface of a pyroelectric sensor. The intensity $j(t)$ of the wave is sinusoidally modulated with the amplitude j and the circular modulation frequency ω_m:

$$j(t)=j_0+je^{-i\omega_m t}. \tag{2}$$

The simulation of the sensor response includes the optical, the thermal, and the electrical modelling. The sensor simulation starts with a calculation of the spatial profile of the electromagnetic wave amplitude in the sensor. The next step is to determine the profile of the absorbed energy density, which forms the distribution of heat sources in the sensor. The thermal sensor modelling delivers the temperature profile, which together with the pyroelectric properties gives access to the sensor signal output.

Of interest is a simulation of the steady state harmonic output signal. A favourable method for the treatment of steady state harmonic thermal problems is the concept of thermal waves.[7–9] The underlying physical mechanism is based on simple pictures, the generation of thermal waves by heat sources, transmission, reflection, and interference. Furthermore, this concept allows a treatment of the optical and the thermal problem with the same algorithms.

Most types of pyroelectric sensors can be considered as a system of parallel faced layers, as schematically shown in

[a)]Electronic mail: bernd.ploss@physik.uni-karlsruhe.de

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