3ω-method In Production Flow For Thermal Flow Sensors

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Abstract

Thermal flow meters represent a vast range of sensors for applications in oil and gas, sustainable energy, food and medical care markets, where precise control of the mass flow is required. As a part of the MEMS production process, testing is performed after product assembly. Due to high customization of products, there are no common tests that can be 'inserted' into the production flow at earlier stages. For some products this results in only half of the chips being approved after testing (low yield). Ever-existing demand on cramming more functional elements while simultaneously reducing footprint for devices poses an additional constraint on potential space for testing.
Performance of thermal flow meters, i.e. penetration and diffusion of the thermal wave, is governed by material properties that in turn are sensitive to variations in process (conditions). In the EFRO OOST Meteorite II research project we develop the test insertions on a wafer to determine effective material properties and serve as process control monitors of wafers quality after front-end production. Specifically, we target the thermal properties of the flow meter's material stack, i.e. thermal conductivity and heat capacity.
For this we use the 3ω-method, in which conductive structures with a positive Temperature Coefficient of Resistance (TCR) are deposited on a wafer and by driving an AC current with angular frequency ω, Joule heating (and thus the resistance modulation) at a frequency of 2ω and a third harmonic because of the TCR in the resulting voltage drop are generated (Fig. 1). The linear slope of the third harmonic AC signal is used to extract the properties of the substrate, and based on this and the total heater response the effective properties of the material stack can be determined (the slope 3ω-method [1]). To determine properties per layer in the stack a reference structure is needed, which comprises the same material stack except the top-most layer and the same heater structure; the difference between original and reference signals defines the properties of the top layer (the differential 3ω-method [2]). We use Comsol Multiphysics to determine optimal designs of the heaters. Comparison of the non-coupled thermal (Heat Transfer module; harmonic perturbation study) and more complex, akin to experiment, electro-thermal coupled physics (AC/DC and Heat Transfer modules; transient study) models showed that the latter has a smaller drop of frequency compared to the more computationally efficient former model, however this impacts a slope slightly (Fig.2). For the first iteration of the test insertions the simplified non-coupled approach was used to perform the parametric sweeping and define the test structures dimensions, namely common line heaters and meandering structures. The latter consists of several parallel line strips with a certain spacing and are spatially-economical in contrast to the line heaters. Based on FEM studies the test structures targeting material properties were determined (Fig. 3), samples fabricated and are currently being validated experimentally. The proposed test insertions methodology is expected to assess the quality of thermal flow meters enabling binning of produced devices based on their measured quality.

Reference

[1] T. Borca-Tasciuc et al., Data reduction in 3ω method for thin-film thermal conductivity determination, Review of Scientific Instruments 72, 2139 (2001).
[2] J. Alvarez-Quintana, J Rodriguez-Viejo, Extension of the 3ω method to measure the thermal conductivity of thin films without a reference sample, Sensors and Actuators A 142 (2008) 232–236.

Figures used in the abstract

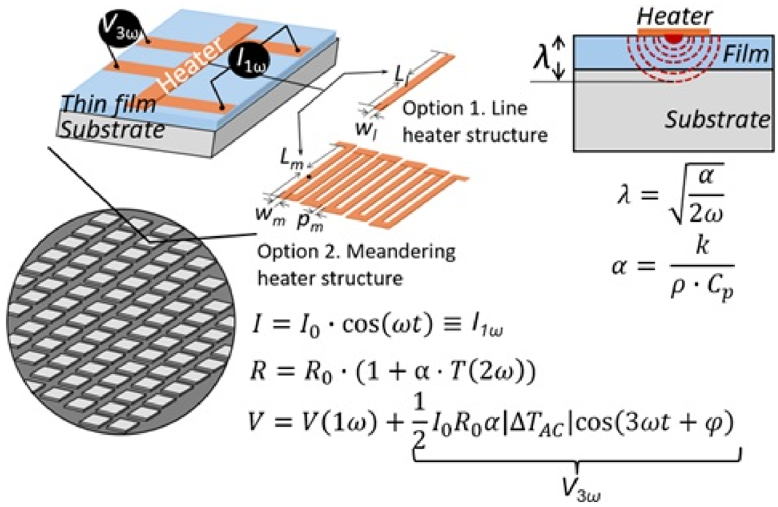

Figure 1 : 3ω-method in wafer level testing: the inserted test structures contain line and meandering heaters. Thermal penetration depth depends on frequency and material properties.

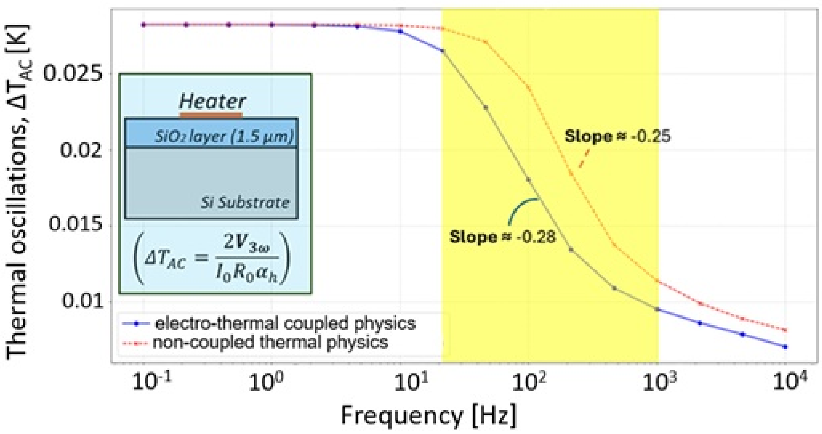

Figure 2 : Coupled vs. non-coupled physics models: the former has smaller drop of thermal oscillations frequency compared to the computationally efficient latter, but slope is similar.

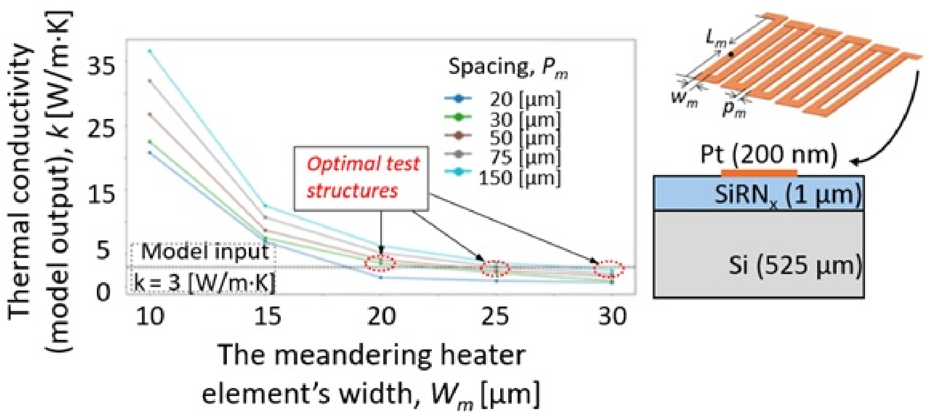

Figure 3 : Example of the optimized meandering heater test structure to determine properties of SiRNx thin film based on the parametric FEM studies (non-coupled modeling approach).

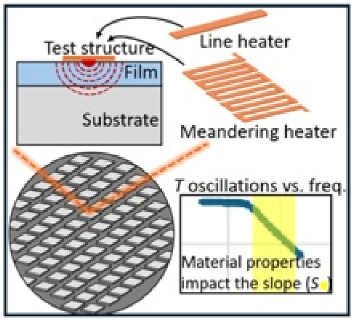

Figure 4 : The test insertions 3ω-methodology to monitor wafers quality after the front-end in production flow for thermal flow sensors.