Characterization of TiO_2 thin film deposited on Silicon membrane using neural networks

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Background – This paper presents a theoretical analysis of the possibility of thermal characterization of a thin TiO_2 film deposited on a 30 μm thick Si membrane as a wafer in the frequency domain of photoacoustics from 20 Hz to 20 kHz. For this purpose, photoacoustic signals generated by such a sample were used (Figure 1) in which the membrane parameters were known and constant, while the film parameters were changed in the ranges of thickness $l_f = (475 - 525)\,\mathrm{nm}$, thermal expansion coefficient $\alpha_f = (1.045 - 1.155)\cdot 10^{-5}\,\mathrm{K}^{-1}$, and thermal diffusivity $D_f = (3.515 - 3.885)\cdot 10^{-6}\,\mathrm{m}^2\mathrm{s}^{-1}$. It can be seen from the Figure 1 that changes in the signal amplitude for the given changes in the film parameters cannot be noticed, while in the phase such changes are clearly noticeable. Within the classical approach of photoacoustic signal processing, non-distinguishing of amplitudes requires the introduction of an additional process of their normalization. In this paper, we will show that well-trained neural networks have no problem distinguishing signal amplitudes and that networks recognize precisely the parameters of thin films on such signals, knowing that the thickness of the films can be two orders of magnitude thinner than their wafers.

Results – The neural networks used in this paper were trained with the basis of photoacoustic signals from Figure 1. The supervised learning algorithm was used by connecting the data of the frequency amplitude-phase characteristics of the input layer signals with the values of the given parameters of the output layer change. The network architecture is very simple and consists of one input (144 neurons), one hidden (10 neurons), and an output layer (3 neurons). The number of input layer neurons corresponds to 144 points that define the photoacoustic signal (72 amplitudes + 72 phases). The three neurons of the output layer are connected to the thin-film parameters: l_f, α_f and D_f. In the case of the thin film thickness, the obtained network performances are 4.3106×10^{-6} for 4 epochs, in the case of coefficient of thermal expansion 3.567×10^{-5} for 7 epochs, and in the case of thermal diffusivity 0.0044842 for 4 epochs. The prediction of neural networks on test signals with errors of less than 1% shows that the networks are sensitive to small changes in TiO_2 parameters.

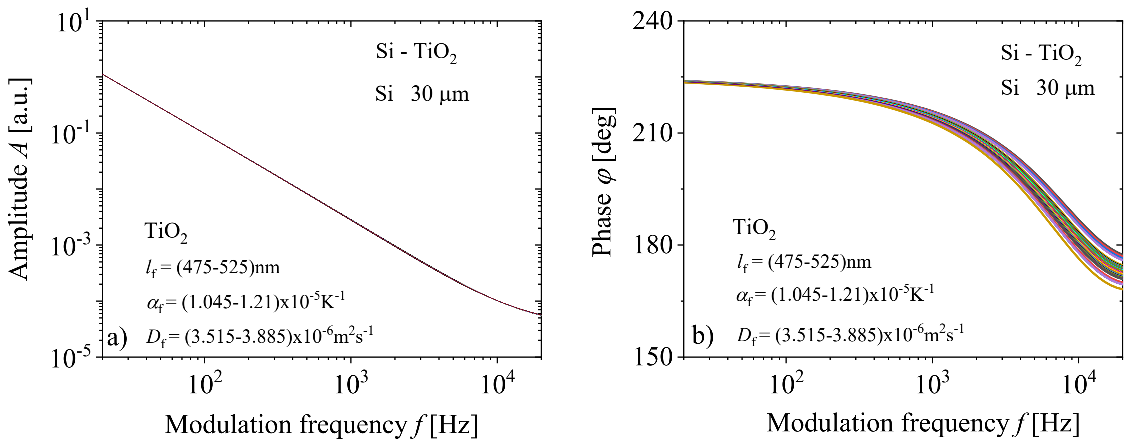

Fig. 1. Photoacoustic signals: a) amplitudes and b) phases of the two-layer model of the TiO2 layer on the Silicon sample obtained by changing the parameters of thickness l_f , expansion α_f and diffusivity D_f of the TiO_2 layer.

Conclusions – Our analysis shows that neural networks have a significant sensitivity to changes in the characteristics of thin layers of TiO_2 deposited on silicon membranes. This fact points to the possibility that neural networks, in combination with photoacoustics, can be a powerful tool in characterizing thin single-layer or multilayer coatings, important for the production of MEMS and NEMS sensors, as well as for the electronics and automotive industries in general.

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