KEYSIGHT TECHNOLOGIES

Calibrated complex impedance of cells at GHz frequencies using scanning microwave microscopy

INTRODUCTION

Scanning Microwave Microscopy (SMM) is an electrical characterization technique used to extract material properties at high frequencies with nanometre accuracy. SMM interfaces two well-known measurement tools, the atomic force microscope (AFM) for materials characterisation and the performance network analyser (PNA) for high-frequency signal measurements.

The AFM allows for nanometre lateral resolution imaging, and the PNA provides high precision impedance and admittance measurements at broadband frequencies from MHz to GHz. The conductive tip acts both as a nanometre scale AFM probe and as a GHz emitter-receiver antenna. The PNA reflection scattering signal S11 is de-embedded and converted to meaningful physical quantities, such as complex impedance, capacitance, and conductance, by means of a calibration procedure[1].

APPLICATION AND RESULTS

For quantitative SMM impedance imaging, we established an ADS based tip-sample circuitry model (Figure 1a) that we combined with 3D finite element modeling using EMPro (Figure 1b). A 3D cell structure has been implemented in EMPro including the cell nucleus, three vacuoles, and a 10nm thick membrane (Figure 1c). The simulated values of the E-field distribution (Figure 1d) and admittance were obtained at 10GHz and at different positions over the cell, in order to investigate how different cell compartments influence the electric field distribution and the admittance values.

Different dielectric values were used for the individual cell compartments including the lipid bilayer of the cell membrane, the cell nucleus, and a vacuole. The modeling results were then compared to experimental complex impedance SMM images (Figure 2). Figure 2, upper panel shows retinal epithelial cells in liquid including topography and raw PNA amplitude and phase data. Figure 2, lower panel, shows the topography and the calibrated impedance images of CHO cells in air including capacitance and conductance. The raw SMM images, acquired at 19 GHz, show the cell structure with high signal levels of 0.5dB in S_{11} amplitude and 1 degree in S_{11} phase with respect to the substrate. The obtained impedance images of CHO cells show a contrast of 550aF (attoFarad) and a conductance of 40µS (micro-Siemens) in the capacitance and conductance image, respectively[2].

CONCLUSIONS

The application of SMM to extract calibrated electrical properties of cells and bacteria[3] in air and in liquid media is presented. From the S_{11} images, after calibration, complex impedance and admittance images of cells have been obtained. The broadband capabilities of SMM have been used to characterise the sample between 1GHz and 20GHz.

The resulting calibrated cell admittance at 19 GHz were roughly $Y_{cell} = 40\mu S + j28\mu S$. A combined circuitry-3D Finite Element Method EMPro model has been developed and used to further investigate the experimental results. The work is a collaboration between University of Linz researcher Silviu-Sorin Tuca and Keysight Labs researcher Matthias Fenner and Ferry Kienberger.

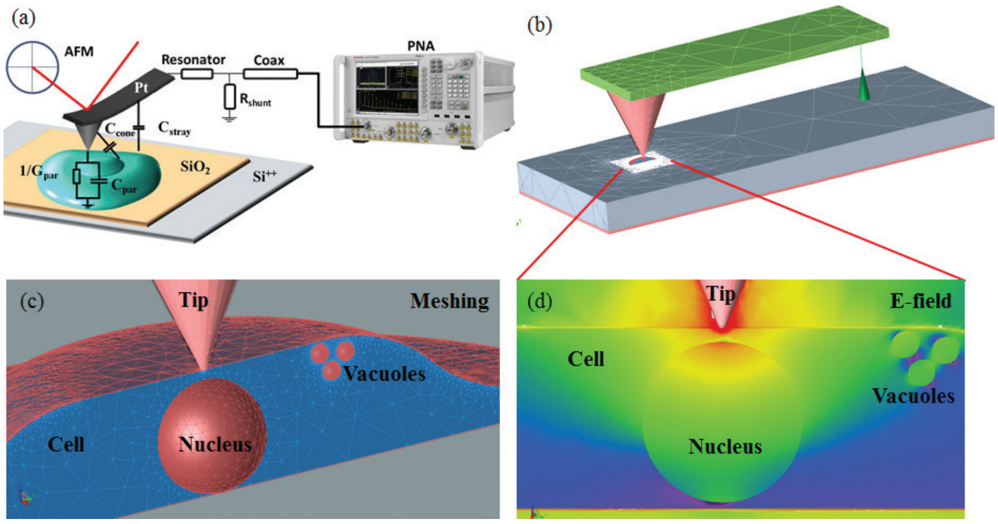

FIGURE 1, top, Tip-cell interaction model and 3D EMPro simulation. In (a) we present the schematic diagram of the SMM system, including the electric circuit and the cantilever stray capacitance. (b) 3D EMPro model mesh of the cantilever, tip, cell, and three-layered Si substrate. (c) zoom-in of the EMPro meshing of the tip-cell interaction point including the cell internal structure (e.g. nucleus, vacuoles). (d) EMPro simulation of E-field over cell surface and penetration into the cell

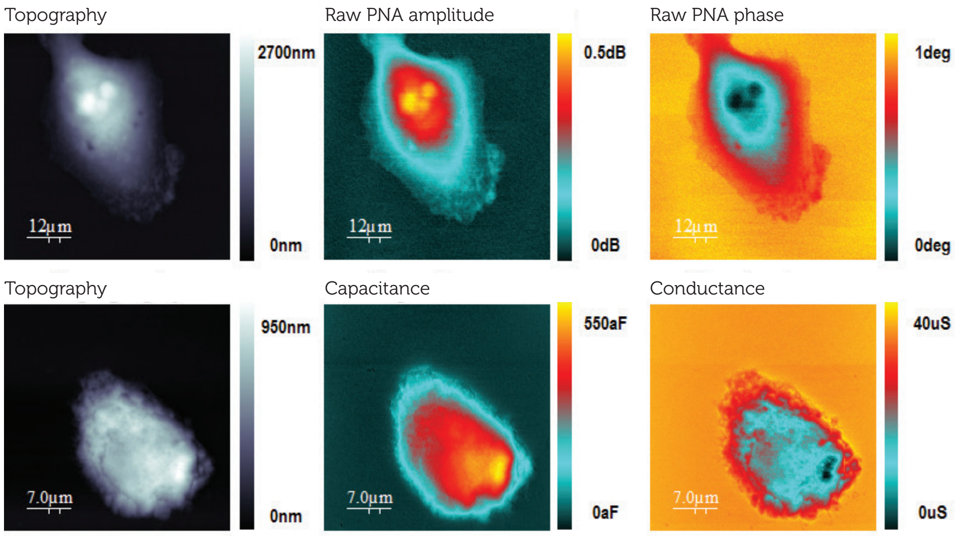

FIGURE 2, above, SMM images of cells in liquid (upper panel) and in air (lower panel). Upper panel: topography, raw microwave signal amplitude and phase of an individual ARPE-19 (Arising Retinal Pigmented Epithelia) cell fixed on Si^{++}/SiO_2 substrate. The cells were imaged in liquid solution of medium, serum, and antibiotics, using ACAFM (tapping mode). Lower panel: topography, calibrated capacitance and conductance of an individual CHO (Chinese Hamster Ovary) cell in air, using ACAFM.

REFERENCES

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