# TOWARDS MICROWAVE AND MILLIMTER WAVE BIOSENSORS

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Bio-sensing by electromagnetic waves from GHz towards THz frequencies, although not yet established as a common method for biomedical applications, offers challenging opportunities, which are complementary to the established optical methods, often based on plasmonic waves and resonances. The longer wavelength - in comparison to visible and IR provides a disadvantage in terms of the smallest possible interaction volume, which can be partially overcome by evanescent field methods. However, the high absorption of micro- and millimetre waves by liquid water, which is the most abundant component of biological substances, provides a unique observation window, which is substantially different and therefore complementary to the other parts of the electromagnetic spectrum.

Our study comprises broad-band measurement and data analysis of the complex dielectric permittivity of bio-relevant liquids, measured by a coaxial probe and a vector network analyser in the frequency range from 100 MHz to 40 GHz. Moreover, a resonant technique based on a ceramic dielectric resonator was employed for analysis of blood samples in microfluidic channels with an interaction volume of less than one micro litre. Finally, first results with an integrated high Q photonic band gap resonator at 100 GHz are discussed, which has a strong potential for the possible realization of a lab-on-chip biosensor.

It is known that species dissolved or dispersed in liquid water usually lead to a reduction of the permittivity and to an increase of the relaxation time. Our study on dissolved proteins in distilled water revealed that the alteration of the static permittivity and relaxation time, as determined by a fit of a single Debye model, depend primarily on the shape and not on the size of the dissolved / dispersed species [1]. Although this specific response appears appealing for use as free-solution biosensor, the applicability is limited to cases of one dominant component in water. Blood represents a simple and therefore appealing system for a practical and useful sensor application at micro-millimetre wave frequencies. Whole blood contains 75 % of water, Hgb (haemoglobin) is the most abundant organic component in blood (approx. 15 g/dl) followed by serum proteins, of which albumin and immunoglobulin are the most substantial (approx. 7 g/dl). The remaining volume is comprised of electrolytes, white blood cells and platelets. Hgb is highly concentrated within the RBCs (red blood cells). The comparison of the complex dielectric permittivity of whole blood with different RBC concentration (haematocrit value) with haemoglobin dissolved in blood serum (blood without RBCs) indicates that above about 5 GHz the effects of the cell membrane and the dissolved electrolytes are not visible [2], which enables a new method for the assessment of the Hgb concentration. Subsequent measurements of the resonant frequency and Q factor with our dielectric resonator – microfluidic assembly of whole blood and serum were performed. As expected from the broad-band measurements, both the difference of resonant frequency and inverse Q factor between whole blood and serum were found to be proportional to the Hgb value, as determined by an established optical method, which relies on lysing of the RBCs [2]. Therefore, the unique advantage of this minimal invasive blood analysis by our microwave-microfluidic system lies in very small volume requirements of below one micro litre, extremely fast diagnostics (seconds) and moderate costs.

At higher frequencies, assemblies like the resonator with separate microfluidic channel are difficult to handle because of tolerances. Therefore, the possible integration of a high-Q resonator array, coupling structures and microfluidics represent a grand challenge aiming towards a lab-on-chip biosensor system. As a first step in this direction, we have investigated photonic crystal defect resonators, which are prepared by deep reactive ion etching from HRS (high resistive silicon) [3]. Our integrated defect resonator with a fundamental mode at 100 GHz was excited by two line defect waveguides in the 2D photonic crystal, which are connected by tapered dielectric waveguide slabs to the WR10 waveguide ports of a vector network analyser. The measured s-

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parameters indicate reasonable matching between the line defect waveguides and the rectangular metal waveguides, a strong coupling leading to about -6 dB insertion loss at resonance and a high loaded and unloaded Q factor of about 5,000 an 10,000, respectively. First sensor applications of this integrated resonator will be discussed.

[1]: T.H. Basey-Fisher et al., Appl. Phys. Lett. 99, 233703 (2011)
[2]: T.H. Basey-Fisher et al., submitted for publication
[3]: W.J. Otter et. al., submitted for publication

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