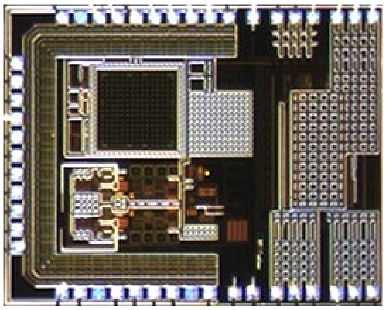
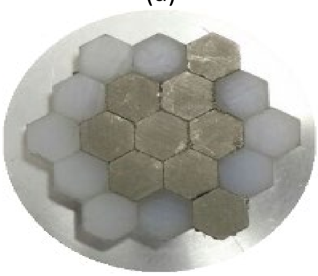
MR-to-go: Making magnetic resonance mobile using integrated circuit technology

Jens Anders[1,2], Jan G. Korvink[3], Bernhard Blümich[4] and Klaus Lips[5]
[1]University of Stuttgart, [2]Center for Integrated Quantum Science and Technology (IQST), [3]Karlsruhe Institute for Technology, [4]RWTH Aachen, [5]Helmholtz-Zentrum Berlin für Materialien und Energie

Recently, the use of integrated circuit (IC) technology has found significant interest in the magnetic resonance (MR) research community for the integration of entire MR spectrometers into application specific integrated circuits (ASICs) with millimeter-size footprints. These NMR-on-a-chip and EPR-on-a-chip spectrometers allow for drastic reductions in the size, complexity, power consumption and cost of MR spectrometers. Moreover, in addition to a pure shrinking of conventional spectrometer electronics, the chip-integration allows for entirely new detection techniques that offer an improved performance e.g. concerning sensitivity and/or broadband detection capabilities [1]. In this invited talk, we will therefore not only discuss portable MR spectrometer realization based on the conventional MR architecture, but also take a closer look into new architectures enabled by the MR-on-a-chip approach. More specifically, in the field of NMR, we will investigate the use of high-voltage CMOS technology for the realization of chip-integrated NMR spectrometer electronics that can directly inject large excitation currents $> 0.5\ \mathrm{A}$ into the NMR coil, thereby removing the need for bulky power amplifiers, cf. Figure 1a. In combination with miniaturized, high-quality NMR coils [2] and NMR-grade permanent magnets [3], cf. Figure 1b, these chip-integrated NMR spectrometers can be used to realize small, lightweight and portable NMR spectrometers. In the field of EPR, the recently proposed voltage controlled oscillator (VCO) based MR detection approach [4], enables performance boosts both at the very high frequency end (hundreds of GHz for high field EPR) and more conventional EPR frequencies in the X-band and Q-band. In this detection approach, the EPR signal is excited by the current running through the coil of a chip integrated VCO and the resulting change in magnetization can be detected as a deviation of the VCO oscillation frequency from its nominal value in the absence of the EPR effect. The VCO-based approach is ideally suited for wide frequency sweeps with (almost) constant sensitivity, thereby allowing for the use of permanent magnets as the source of the static B_0-field [4]. This in turn allows for the design of portable EPR spectrometers, cf. Figure 2a. As demonstrated in [5], the VCO-based approach is also ideally suited for the formation of large scale detector arrays to enhance the concentration sensitivity. Here, in contrast to the conventional resonator-based approach, the readout complexity does not increase with the number of array channels, which in combination with the use of CMOS technology for the detector realization allows for large channel counts, cf. Figure 2b. The presented portable MR systems bear the potential to turn MR-based analytics into an affordable in-field method.

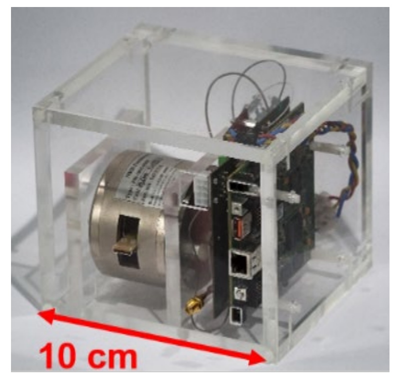


(a)

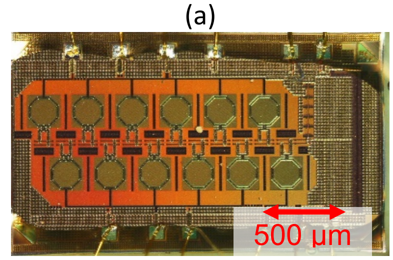


(b)

Figure 1 (a) Micrograph of a monolithic NMR-on-a-chip spectrometer and (b) magnet assembly for a yoke based permanent NMR magnet



(a)



(b)

Figure 2 (a) Portable EPR spectrometer based on an EPR-on-a-chip detector and (b) micrograph of a chip-integrated array of EPR detectors.

[1] J. Handwerker, J. Anders: IC-Based and IC-Assisted µ NMR Detectors. In: *Micro and Nano Scale NMR* (2018).

[2] N. Spengler, J. Höfflin, A. Moazenzadeh, D. Mager, N. MacKinnon, V. Badilita, U. Wallrabe, J.G. Korvink: Heteronuclear Micro-Helmholtz Coil Facilitates µm-Range Spatial and Sub-Hz Spectral Resolution NMR of nL-Volume Samples on Customisable Microfluidic Chips. In: *PloS one* 11 (2016), S. e0146384-e0146384.

[3] B. Blümich, C. Rehorn, W. Zia: Magnets for Small-Scale and Portable NMR. In: *Micro and Nano Scale NMR* (2018).

[4] B. Schlecker, A. Chu, J. Handwerker, S. Kiinstner, M. Ortmanns, K. Lips, J. Anders, VCO-based ESR-on-a-chip as a tool for low-cost, high-sensitivity point-of-care diagnostics, 2017 IEEE SENSORS, 2017, pp. 1-3.

[5] A. Chu, B. Schlecker, K. Lips, M. Ortmanns, J. Anders, An 8-channel 13 GHz ESR-on-a-chip injection-locked VCO-array achieving 200 µM concentration sensitivity, 2018 IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC), San Francisco, USA, 2018.