Title
Life Sciences and the future of sensory testing

Company
NXP Semiconductors N.V. (NASDAQ: NXPI) creates solutions that enable secure connections for a smarter world. Building on its expertise in high-performance mixed signal electronics, NXP is driving innovation in the areas of connected car, security, portable & wearable, and the Internet of Things. NXP has operations in more than 25 countries, and posted revenue of $5.65 billion in 2014.


Applicant
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Problem description
Today all complex electronic devices (mobile phones, smart watches, laptops, tablets, PCs, etc.) are based on CMOS (Complementary Metal–Oxide–Semiconductor) chips that provide unprecedented computing power on an area of just a few mm² at extremely low power consumption. This is the result of 45 years of aggressive down-scaling of the minimum features sizes of transistors and metal interconnect wires in CMOS chips; a trend described by Moore’s famous law. Current modern CMOS chips have feature sizes of 10 – 15 nm, i.e. smaller than the smallest viruses, and comparable to dimensions of biomolecular objects like antibodies, cell receptors, etc.

Several years ago NXP has recognized this as an opportunity to design a true CMOS-compatible¹ electronic biosensor chip. The chip, made in a commercial 90-nm CMOS process, contains a dense array of 256 × 256 gold nanoelectrodes² with a diameter of 170 nm, placed on a rectangular 600 nm × 890 nm grid. Depending on the application, functional groups can be attached to the nanoelectrode surfaces, e.g. by means of a self-assembled monolayer. In contact with water the electrodes form tiny nanocapacitors with electrode capacitances typically in the 0.2 – 2 fF range.³ Individual electrode capacitances are measured with on-chip electronic circuits with a resolution of about 1 aF, and converted to digital values with on-chip analog-to-digital converters. The capacitances are measured at high modulation frequencies (1 – 50 MHz) to overcome Debye screening by mobile ions in solution. A complete row of 256 nanoelectrodes is measured at once, and the row is scanned through the array (similar to the scanning of rows of pixels in an optical image sensor chip). This way a capacitive (instead of optical) picture can be recorded with a frame rate up to 10 frames/s. In combination with frequency sweeps this provides imaging capability with sub-micron spatial resolution and spectroscopic contrast.

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¹ True CMOS-compatibility is more than just “being made of and/or on silicon” (an opportunistic interpretation of CMOS-compatibility, used in almost every scientific publication). Instead it means: “combined with, or made of fully functional CMOS electronics circuits on the same chip that is manufactured in a commercial CMOS factory”.
² The CMOS factory manufactures the chips with copper nanoelectrodes. In a post-processing step the copper is converted into a gold-rich gold-copper alloy and polished to a smooth surface finish.
³ 1 fF (femtoFarad) = 10⁻¹⁵ F (Farad); 1 aF (attoFarad) = 10⁻¹⁸ F (Farad).
The array sensor potentially can serve a wide variety of applications, e.g. imaging of living cells, detection of micro- and nanoparticles, massively parallel bio-assays, DNA sequencing, etc. The high modulation frequency enables reproducible quantitative capacitance measurements that fit well to analytical and numerical models. Some of the sensor chip’s capabilities have been demonstrated in a recent Nature Nanotechnology publication [1], and were immediately recognized by some experts in the field [2, 3]. Models and numerical simulations are described in a few recent journal articles [4, 5] and references therein.

Because of the array architecture of the sensor chip it generates a huge amount of data that can be processed in many different ways, e.g. by statistical signal processing algorithms. This can be done from the lowest level (filtering, noise reduction, etc.) all the way to the high level (hypothesis testing, decision making, etc.).

Despite the huge potential of the electronic biosensor chip it was extremely difficult to make a “hand shake” with potential customers like diagnostic companies. The strictly model-based way of working of semiconductors companies like NXP is completely different from the largely empirical way of working of “bio-companies”. This creates a huge communication barrier between the two “worlds” that severely impedes bridging the gap between unmet needs of one partner by offered solutions by the other (and vice versa).

The challenge to the team is to connect the biosensor chip’s capabilities to applications with large potential market volume. Preferably by describing 1 or more use cases in some technical detail (as far as possible in the limited time available), using a “language” that is appreciated by both parties (NXP and potential customers). The breakthrough provided by the proposed use case should outweigh the perceived risk of the paradigm change that comes with moving from known detection methods (typically optical) to the new capacitive detection method. More technical information is available from the applicant on request.

References


4 By nature CMOS technology is optimized for low-cost large-volume production. Applications with small market volumes often cannot benefit from this because of the high design cost of CMOS chips.