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RFID sensor chips with anticollision algorithm for simultaneous detection of multiple DNA target

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1. Introduction

This paper describes an electronic reagent for a point of care testing (POCT) device that provides a portable and inexpensive DNA-measuring system by adopting a tiny disposable sensor head. Here, a data-transmitting interface in which an electrical socket is used to connect the sensor head and a controller could likely pose various problems in terms of socket cost, hermetic sealing of the sample to prevent infection/contamination, and flexibility in the number of targets. These problems should be solved by introducing an RFID sensor with wireless interface for data transmission. The RFID sensor chip has a sensor and RF communication circuit as well as an antenna coil on a 2.5 x 2.5-mm silicon chip. Previously, we demonstrated DNA measurement with a first-stage prototype "RFID sensor-I" [1], in which one photo-sensor chip was driven to measure one DNA target. In the present work, we demonstrated a simultaneous multiple-target measurement using newly developed RFID sensor-II chips. For this goal, it was necessary to develop (i) a low-power control logic and (ii) a reproducible random number generator (RRG). Finally, bioluminometric DNA measurement was carried out using multiple RFID sensor chips with a photo-sensor and temperature sensor.

2. Experimental and Results

System configuration

Figure 1 illustrates a block diagram of the RFID sensor-II chip. For peak power reduction we have adopted a clock gating technique in the control logic consisting of four circuit modules. Figure 2 shows micrographs of the presented RFID sensor chips fabricated by the 0.35-μm CMOS process. Peak power was calculated to be reduced from 2443 μW for RFID sensor-I to 1018 μW. This leads

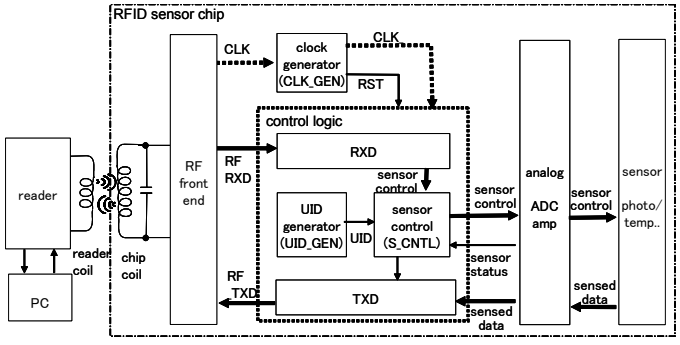

Fig. 1 Block diagram of RFID sensor chip

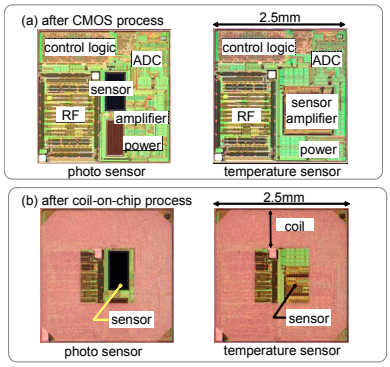

Fig. 2 Chip micrographs of RFID sensor chips

to an expanded communication distance from 1 mm to 3 mm and to increased communication stability for multi-chip operation in the reaction cell.

The RFID sensor is basically compliant with ISO15693, the standard defining an eight-byte UID. Two bytes out of the eight-byte UID field were assigned for a reproducible random number (r-random#). Then, a reproducible random number generator (RRG) using MOSFET characteristic fluctuation was developed. As shown in Figure 2, the RRG circuit is fully compatible with standard CMOS processes. The outputs of two inverters, functioning as "offset detector," are differentially amplified by and rectified by a "comparator." By the "AND" stage, the comparator output is latched. If the offset is comparable to or smaller than the random noise, the output value might result in a non-reproducible value. For this, the results of "1" and "0" are counted by a "counter" stage, and the bit number is decided by the majority. By introducing this bit-sampling, the possibility of obtaining a non-reproducible state was calculated to be 4%, which is half the 8% in the case without multiple bit-sampling. The bit-error showing a non-reproducible state was experimentally evaluated to be 2 bits out of 96 bits, which approximately agrees with the calculation and is an acceptable performance for the multiplication around five targets.

The photo-sensor and analog circuit are basically the same as in the RFID sensor-I. The chip includes two photodiodes, PDsig and PDref, each of which has an active sensing area of 0.325 x 0.65 mm. The cathode voltages of PDsig and PDref are differentially amplified to eliminate dark current and are digitized by a 13-bit ADC with a ΔΣ

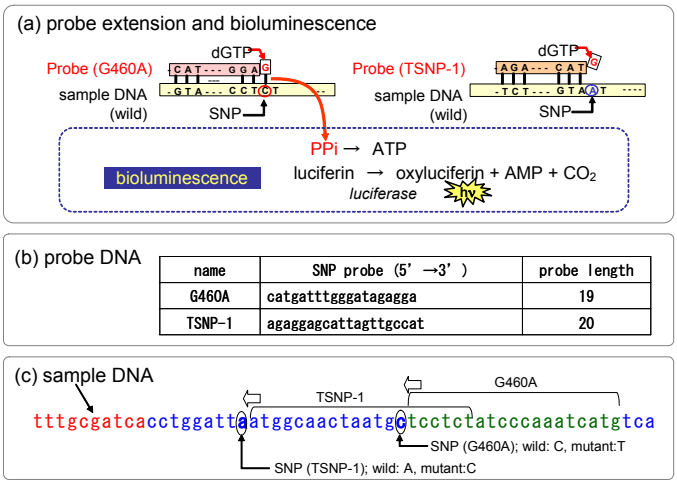

Fig. 3 DNA assay using bioluminometry

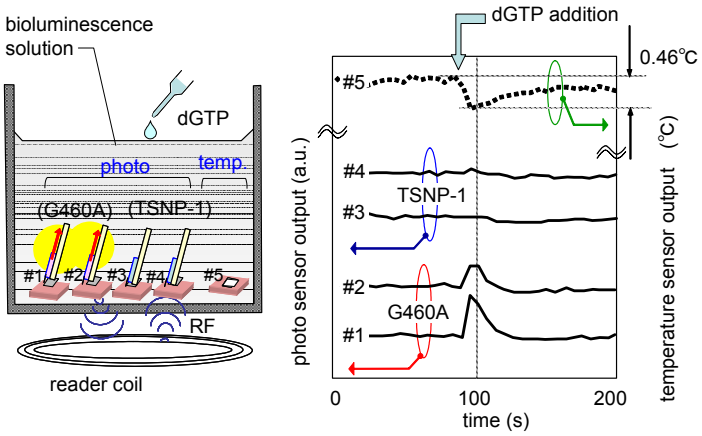

Fig. 4 Multiple-target DNA measurement

modulator. For RFID sensor-II, the offset level can be shifted by the control commands from the PC within the range of ±100 mV. Figure 3(b) illustrates a circuit configuration of a temperature sensor block in the RFID temperature sensor. Based on a reference voltage VBGR and temperature-dependent current I1, temperature is converted to voltage and digitized by a 13-bit ADC. Sensitivity and offset level can be adjusted by control commands from a PC. The operating range of the chip was experimentally evaluated to be -20°C to 180°C. Data fluctuation was less than 0.2°C, and reproducibility was within 0.5°C.

Bioluminometric measurement of multiple DNA target

Figure 3(a) shows the bioluminescence reaction that was used for DNA measurement. Single nucleotide polymorphisms (SNPs) can be measured by observing bioluminescence using the single-base probe-extension [4]. Sequences of probes and sample DNA are shown in Figure 5(b) and (c). For the wild type of G460A, guanine (G) is incorporated into the probe edge (3'-terminal) because it is complementary to cytosine (C); then pyrophosphate (PPi) is released. Next, PPi is converted into ATP by ATP sulfurylase, followed by photo emission. For the wild type of TSNP-1 (SNP site is "A"), where "G" is not incorporated into the primer 3'-terminal, photoemission is not induced.

The measuring set-up for multiple-SNP detection is shown in Figure 4 (left). Biotinized probe oligomers were immobilized on avidin-coated RFID photo-sensor chips [5]. Two sensor chips with immobilized probes were prepared with each of the G460A (chips #1, #2) and TSNP-1 (chips #3, #4) probes. These four photo-sensor chips and one temperature sensor chip (#5) were set in a reaction cell with a diameter of 9 mm. Then bioluminescence-reaction solution (30 µl) containing sample DNA (wild type, 8 pmol) was introduced to the reaction cell. Figure 4 (right) illustrates time courses of the signal from the photo-sensors and temperature sensor. SNP typing for the wild-type G460A sample was properly carried out; that is, on adding a guanine base in the form of dGTP (deoxyguanosine triphosphate), bioluminescence was clearly detected only from the sensor chips with the corresponding probes. At the same time of dGTP incorporation, a slight temperature decrease (0.46°C) was observed.

3. Conclusions

RFID sensor, consisting of sensor and passive wireless interface for data transmitting, was applied to a simultaneous multiple-DNA target measurement. For anticollision control to achieve a flexible operation of different kind or different number of sensor chips, a peak power of the sensor chip was reduced down to 1018µW by a clock gating technique and a reproducible random number generator utilizing MOS characteristics fluctuation was developed. Simultaneous operation of four photo-sensors and one temperature sensor was demonstrated.

Acknowledgements

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References

[1] Y. Yazawa, T. Oonishi, K. Watanabe, R. Nemoto, M. Kamahori, T. Hasebe, and Y. Akamatsu, "A Wireless Biosensing Chip for DNA Detection," ISSCC Dig. Tech. papers, pp. 562-563, 2005.

[2] M. Philipose, J.R. Smith, B. Jiang, A. Mamishev, R. Sumit, K. Sundara-Rajan, "Battery-free wireless identification and sensing" Pervasive Computing, IEEE, Volume 4, Issue 1, pp. 37-45, 2005.

[4] M. Ronaghi, M. Uhlen, and P. Nyren, "DNA Sequencing: A Sequencing Method Based on Real-Time Pyrophosphate," Science, issue 281, pp. 363-365, 1998.

[5] S.-J. Han, H. Yu, B. Murmann1, N. Pourmand, S. X. Wang, "A High-Density Magnetoresistive Biosensor Array with Drift-Compensation Mechanism," ISSCC Dig. Tech. papers, pp. 168-169, 2007.