Development of 60 GHz Near-field Array Sensor

Yuichi Ogawa

Kyoto University (ogawayu@kais.kyoto-u.ac.jp)

Summary: Water molecules are the essential constituent substances in cells, but it has been difficult to measure their dynamics with conventional techniques. The spectroscopic information of the hydrogen bond network of water molecules lies in the sub-terahertz region. To detect the state of water, we focus on frequencies around 60 GHz and have been developing a CMOS biosensor integrated circuit (IC) with 60-GHz oscillator array. This presentation introduces the concept of this unique sensor and the results of first experiments and shows the possibility of future application.

Introduction: *WATER* is one of the exciting research objects in terahertz spectroscopy. Pioneering research has unraveled the dynamic movement of water molecules, which contributes to understanding the interaction between solute molecules and water molecules. I think the key technology here is THz time-domain spectroscopy based on ultrashort laser system. Since such optical technology provides us with a wide variety of measurement methods, and they are beneficial for basic research. On the other hand, despite the efforts of many researchers to enable measurement of such water molecule dynamics, many of the important materials of life science researchers are in their laboratory. We can't bring the more important and valuable medical samples out of the room or building. In other words, we have to make an effort to bring out terahertz technology. The technology of the electronic device which can be small and highly integrated is useful in such a situation. In this presentation, I will introduce a sensor using 60 GHz oscillator and its application.

Principle: As the concentration of solute molecules increases, the quantity of the water molecules that contributes to the relaxations decreases. The resultant changes in the relaxation spectrum become particularly prominent in a frequency range around 100 GHz. The sensor utilizes LC oscillators of 60 GHz to detect the changes in the complex dielectric constant of a target. It consists of 1488 CMOS transistors oscillating at 60 GHz, and individual operation of each element is possible. It is designed to oscillate at a frequency of 60 GHz when the top of the element is air. The dielectric characteristics of the object are estimated by the oscillation frequency shift when the target material comes into contact with the sensor surface. The size of one element is 110 μm × 51 μm, and all elements are arranged in 3 mm square. It operates as a near-field image sensor and can acquire data of all elements within 0.5 seconds.

Experiments: It is known that the dielectric constant of distilled water increases as the temperature rises. The distilled water of different temperatures was measured as a sample to confirm the operation of our sensor.

Figure 1 shows the measurement results. The horizontal axis indicates the frequency shift amount from the reference frequency (60 GHz), and the higher dielectric constant (higher temperature) shows a large shift. In this graph, the vertical axis indicates the ratio of the number of elements having a particular frequency shift to all the elements (1488). The spread of the shift amount is considered to reflect the characteristics of each element and temperature nonuniformity in the measurement region.

Figure 2 shows the measurement results of HeLa cells cultured on the sensor directly and culture medium (DMEM) at 37℃. The frequency shift amount of DMEM became smaller than that of distilled water (37℃). This is mainly because the number of water molecules has decreased relative to the substance dissolved in DMEM. On the other hand, cultured cells showed a broad distribution with a peak around 1.68 GHz. Since the size of one element of this sensor is larger than that of a cell, the density of cells per element changes the frequency shift amount. Furthermore, nuclei and organelles are also distributed in the cells, and these heterogeneities are considered to be responsible for broadening of the frequency shift amount. However, it is anticipated that this distribution also includes differences in cell cycle and cell state. I want to develop a technology to analyze these information and measure the cell quality and the details of cellular water.

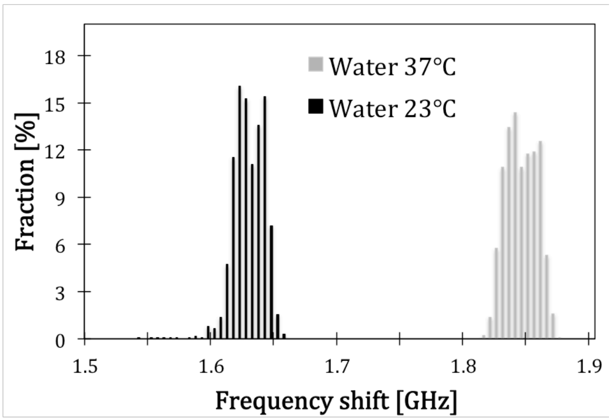

Figure 1. Amount of shift by distilled water at different temperature

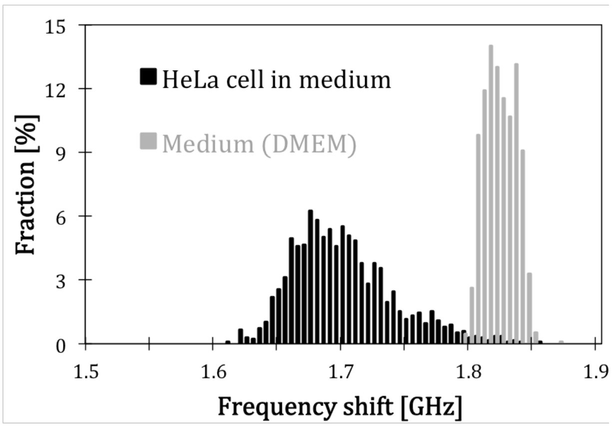

Figure 2. Comparison of cultured cells (confluent) and culture medium