ANALOG IMAGE SENSOR FOR HIGHLY-SENSITIVE SPECTROSCOPIC IMAGING

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ABSTRACT

In this paper, we propose a highly sensitive laser spectroscopic imaging method without scanning process. We have investigated analog signal processing circuits, which are supposed to be installed to each pixel of a CMOS image sensor. In the imaging method, modulated signal is extracted from background before signal digitization. It gives wider dynamic range compared to conventional image sensors, including our former report [1]. The imaging time is also much shorter than scanning imaging methods [2]. We designed the circuits for photothermal spectroscopy as an example of application, where the high background signal must be removed for highly-sensitive detection.

KEYWORDS

Analog signal processing, Imaging, Photothermal spectroscopy

INTRODUCTION

Highly sensitive and fast spectroscopic imaging is a prospective tool for observing biomolecule behavior. In general, high sensitivity can be achieved by signal recovery process with modulation and demodulation. For demodulation process, frequency selective detections device such as a lock-in amplifier are commonly utilized. On the other hand, fast imaging is achieved by non-scanning imaging process with detector arrays such as an image sensor. It is difficult to install the demodulation device to each pixel of the to image sensor. Grauby *et al.* [3] has developed a demodulation process with image sensor, which utilizes synchronous detection of the modulated signal and digital signal processing extracting the targeted component in the digitized signal. However, its sensitivity has been inferior to the lock-in amplifier because the background component cannot be removed before the signal digitization. The digitized background limits the gain of signal amplification which is required to detect weak signal hindered by noise. In this paper, we propose an analog signal processing method, which is supposed to be installed to the image sensor. By installing background filtering and amplification circuits on each pixel of image sensor, the signal can be amplified sufficiently before digitization. As an example of the circuits, we designed an analog electrical circuit for photothermal spectroscopy. The feasibility of the analog signal processing is investigated by detecting the photothermal signal, obtained with a photodiode as a model system.

CONCEPT

Figure 1a shows a conventional imaging system with a laser-scanning process. In the imaging of trace amounts of analytes in micro devices, the signal is recovered by using a lock-in amplifier in order to gain high S/N and/or S/B. However, it requires long-time (slow) scanning. Figure 1b shows a novel imaging method with an image sensor. In this conception, the image sensor two-dimensionally detects the modulated signal. Frequency-selective detection is achieved by analog electrical circuits on each pixel of the image sensor as shown in Figure 2.

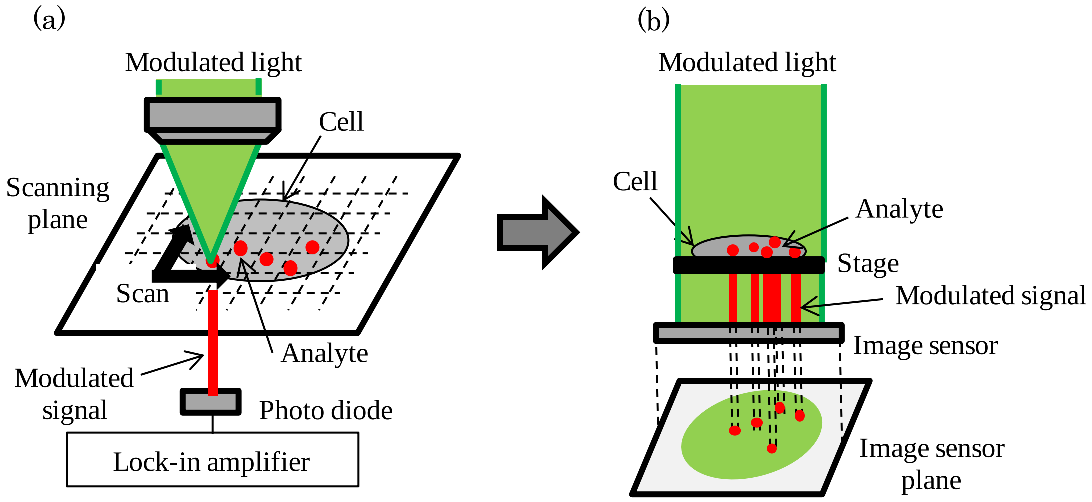

Figure 1. Concept of laser imaging methods. (a) Imaging method with scanning process. Modulated signal is extracted from background by lock-in amp. (b) Imaging method with an image sensor. Modulated signal is two-dimensionally detected.

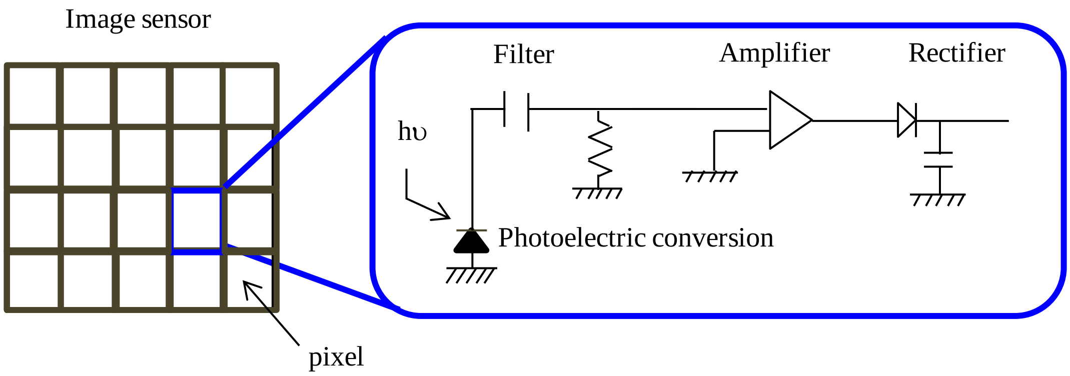

Figure 2. Concept of frequency-selective detection system with an image sensor. The analog electrical circuits for removal of background are installed on each pixel of an image sensor.

EXPERIMENTAL

The analog circuits were designed for photothermal spectroscopy with a photodiode (PD). Non-fluorescent analyte absorbs excitation light, release thermal energy via non-radiated relaxation, and generates the temperature distribution corresponding to refractive index distribution. The refractive index distribution acts as a transient lens and modifies the locus of the probe light. The analyte concentration can be determined by measuring the degrees of the lens which are proportional to the absorbance of the excitation light.

Figure 3a illustrates the experimental setup. The excitation and probe beams are modulated by the acoustic optical modulators (AOM), coaxially aligned, and focused in dye solution sample (SudanⅣ in toluene) in a microchannel. The excitation and probe beams were modulated at 1743 Hz and 2010 Hz, respectively. In this case, photothermal signal was detected as a beat signal. Figure 3b illustrates the scheme of the modulation and the interfered beat signal. The beat has a frequency equal to the difference between two modulation frequencies (267 Hz). Figure 3c shows the block diagram of the signal processing. The signal of 267 Hz is selectively filtered by a bandpass filter (BPF) and amplified by an amplifier. Then, the amplitude is converted to DC signal by a rectifier. The signal is fed into an A/D convertor and recorded by PC.

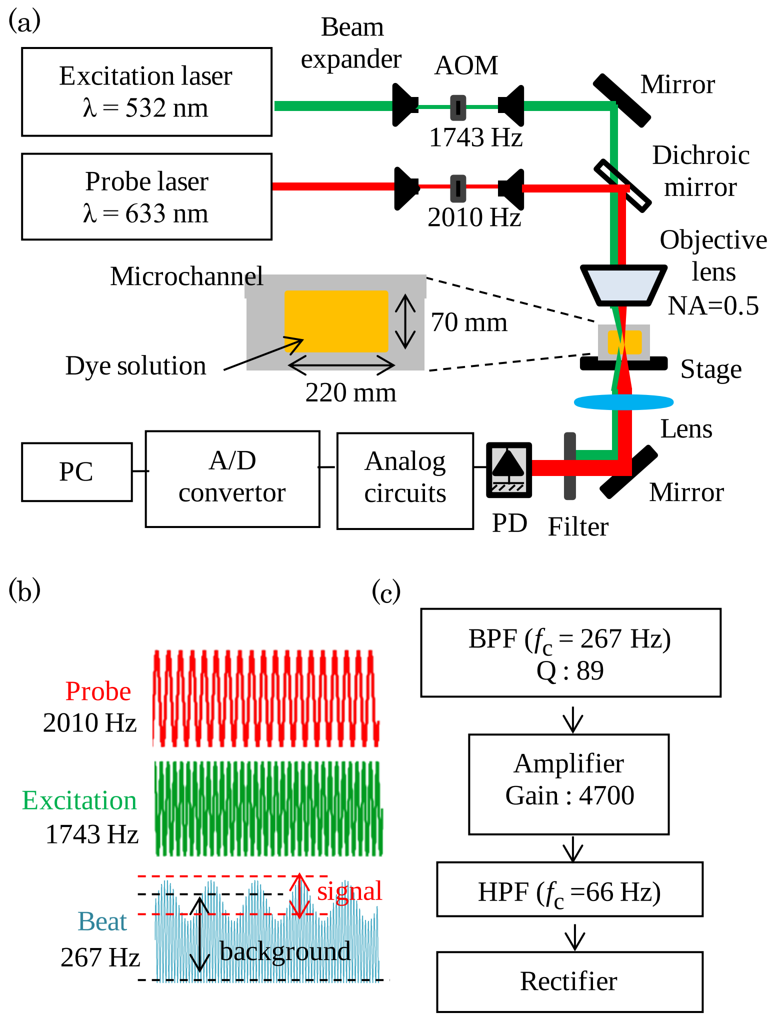

Figure 3. (a) Experimental setup of photothermal spectroscopy. (b) Scheme of the modulation and the interfered beat signal. (c) Block diagram of analog electrical circuits for beat signal detection.

RESULTS AND DISCUSSION

Figure 4 shows an example of the calibration curve. The signal was averaged for 10 seconds. The sample of 1.0×10^{-7} M (1.9×10^{-5} abs.) gave 0.183±0.005 V. As shown Table 1, it is equivalent to the sensitivity of thermal lens imaging with CCD detection [1], and lower than that of TLM with lock-in amplifier [2]. From the S/N at the concentration, the detection limit of 5.0×10^{-9} M (9.5×10^{-7} abs.) was expected, but the signal of 5.0×10^{-8} M was not distinguished with the blank because of the rectifier character. After improving the character, much lower detection limit is expected.

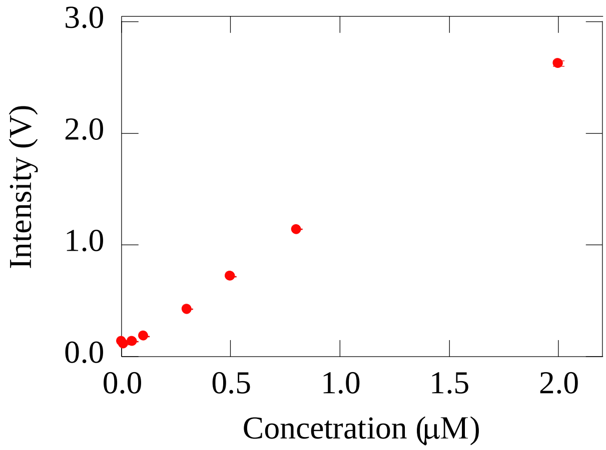

Figure 4. Calibration curve of photothermal signal obtained with analog electrical circuits.

Table 1. Comparison of imaging systems for photothermal detection. The sensitivity of CCD detection was measured by using previously developed method [1].

	Imaging	Sensitivity (absorbance)	Time resolution
PD with lock-in amplifier	○	10^{-6}~10^{-9}	min - hour
CCD detection	○	1.4×10^{-5}	sec
PD with analog circuits	×	1.9×10^{-5}	sec

↓ ○ Enabled by CMOS sensor

CONCLUSIONS

In this paper, we have investigated a highly sensitive laser spectroscopic imaging method without scanning process with a photodiode-analog-circuit model. We have investigated the analog signal processing method for the image sensor. The detection limit of TLM with the circuits was 1.9×10^{-5} abs. In the future work, we will integrate the optimized circuits on CMOS image sensor for realizing a novel imaging method.

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