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Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp840-841

Light source modulated and oxygen annealing NbO_x/Si-LAPS for hydrogen ion image sensor

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Abstract

A LAPS device with NbO_x sensing membrane was fabricated to evaluate effects of light signal modulation for high photo voltage in 20 kHz operation. High amplitude and short wavelength laser are suggested for high output signal. In addition, RTA in O_2 ambience at different temperature was performed to have a stable pH sensing performance. NbO_x-LAPS with RTA at 700^{o}C in O_2 ambience could be a choice for pH image sensor by operating with micro mirror.

1. Introduction

Light addressable potentiometric sensor (LAPS) is an important label free device for a two dimensional distribution of chemical species detection proposed by Hafeman in 1988 [1]. Based on the operation of electrolyte-insulator-semiconductor (EIS) structure and ion-sensitive field-effect transistor (ISFET), LAPS works with additional modulated light source which can be used to scan the sensing area to obtain photo voltage distribution for 2 dimensional chemical image [2, 3]. The local photocurrent in LAPS can be generated by focusing modulated light source into the depletion layer by the reversed bias in semiconductor layer. [4] The concentration change in the analyte makes the shift of response curve of LAPS. Light spot area and size will determine the image of LAPS. [5] To have a 2D chemical image with high spatial resolution (~1 um) in a short time (<1 sec), ac signal of light source worked in a high frequency and corresponding high output photocurrent are required. In this study, a light modulation by different wavelength, frequency and amplitude was carried out to investigate the photo voltage of niobium oxide (NbO_x) LAPS. In addition, rapid thermal anneal (RTA) is also given to improve pH sensing performance.

2. Experiment

LAPS with single NbO_x layer deposited by radio frequency rf sputtering directly on p-type (100) silicon wafer. Nb target with 99.9% purity was used in reactive rf sputtering with flow rate of Ar and O_2 for 20 and 5 sccm, respectively. Then, the PDA was performed in O_2 ambient at temperature of 500, 700, and 900°C for 1 min, respectively. [6] Detail process flows of all groups are shown in Fig. 1 (a). Photo current was changed to photo voltage by an additional resistance. pH sensitivities of sensing membranes were extracted by photo voltage-voltage (V-V) curves of LAPS measured in various pH buffer solutions. through Ag/AgCl reference electrode by the setup shown in Fig. 1(b).

3. Results and discussion

Figure 2 shows the frequency effect on the photo voltage to substrate bias on NbO_x-LAPS without treatment. Photo voltage was increased from 500 Hz to 1 kHz then decreased to 20 kHz. To have a high signal to noise ratio, high photo voltage as output signal has to be as high as possible. High frequency of ac signal to provide light intensity gradient is necessary for high scanning speed. Less photo voltage is generated by 20 kHz ac signal, which is a constraint of high scanning speed in LAPS for chemical image sensor. Therefore, Vpp of ac signal is also modified to check photo voltage as shown in Fig. 3. High photo voltage can be obtained by high Vpp. No higher DC bias can be given by our function generator due to the power limitation. Furthermore, short wavelength red laser with same intensity was used to increase output photo voltage as shown in Fig. 4. It is obviously seen that short wavelength laser will have higher photo voltage by higher energy of photons. pH sensing performance of NbO_x-LAPS is shown in Fig. 5. Sensitivity in different light signal can be calculated by the linear fitting between pH and corresponding substrate with normalized output photo voltage in 50%. Sensitivity and linearity are comparable between low and high frequency setting. Hysteresis effect could be checked by output signal in pH loop of pH 7-4-7-10-7 with 10 min in each step as shown in Fig. 6. To have better pH sensing performance, RTA with different temperature was performed in O_2 ambience. A detail comparison of pH sensing properties is listed in Table 1. Figure 7 shows the surface roughness by AFM analysis. Higher pH sensitivity could be obtained in higher RTA temperature, especially in 700^{o}C O_2 ambient.

4. Conclusion

To have a higher photo voltage in high frequency operation, amplitude of ac signal and wavelength of laser were investigated for NbO_x-LAPS in pH 7 buffer solution. High amplitude and short wavelength laser are suggested. With 20 kHz ac signal, 2k points of NbO_x-LAPS with RTA at 700^{o}C in O_2 ambience could be scanned and obtained within 1 sec for pH image sensor by using analog micro mirror in the future.

Acknowledgement

This work is supported by the National Science Council of the Republic of China under the contract number of NSC 101-2218-E-182-004.

References
[1] D. G. Hafeman, et al., Science 240 (1988)1182–1185.
[2] M. Nakao, et al., Sens. Actuators B 34 (1996) 234–239.
[3] T Yoshinobu, et al., Electrochimica Acta, 47 (2001) 259-263.
[4] O. Engström, et al., J. Appl. Phys. 54 (9) (1983) 5245-5251.
[5] W.J. Parak, et al., Sens. Actuators A 63 (1997)47–57.
[6] T.-W. Chiang, et al., SSDM 2012, pp.380-381.

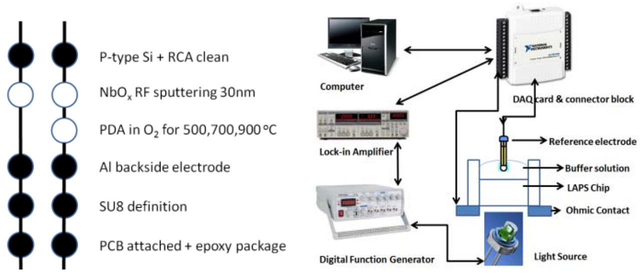

Fig. 1 (a) Process flow of NbO_x-LAPS structures with PDA in O_2 ambience, and (b) LAPS measurement setup.

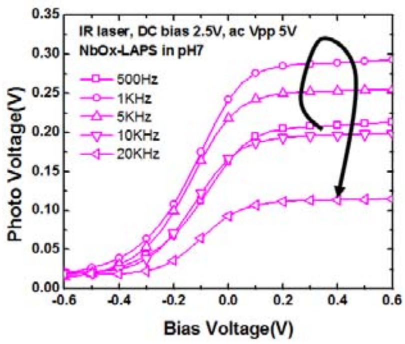

Fig. 2 Photo voltage versus bias voltage of NbO_x-LAPS without treatment measured in pH 7 impacted by ac signal frequency of IR laser diode.

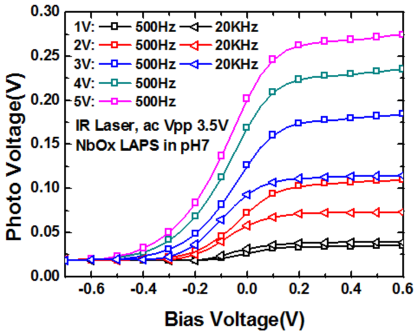

Fig. 3 Photo voltage versus bias voltage of NbO_x-LAPS measured In pH 7 impacted by ac signal amplitude of IR laser diode in (a) 500 Hz and (b) 20 kHz

Table 1 pH sensing performance of NbO_x-LAPS for all experimental groups.

Light Source	temp(oC)	Sensitivity(mv/pH)	Linearity(%)	Hysteresis(mV)
Red Laser	0	54.1	96.85	-0.33
	500	56.3	99.69	-1.45
	700	58.5	99.77	6.19
	900	55.3	99.99	16.02
IR Laser	0	60.61	99.93	-20.82
	500	58.85	99.38	12.57
	700	61.87	99.98	2.53
	900	54.44	99.97	-4.22

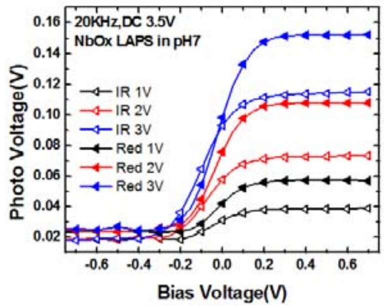

Fig. 4 Photo voltage versus bias voltage of NbO_x-LAPS without treatment measured in pH 7 impacted by ac signal amplitude of (a) IR and (b) red laser diode in 20 kHz.

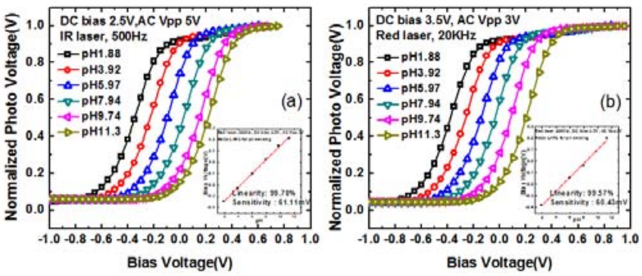

Fig. 5 Photo voltage versus bias voltage of NbO_x-LAPS with different RTA treatment measured in various buffer solutions and corresponding fitting sensitivity for optimized light condition in (a) 500 Hz and (b) 20 kHz.

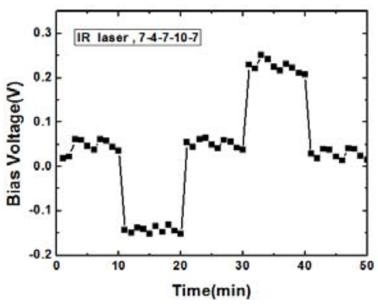

Fig. 6 Typical hysteresis response of NbO_x-LAPS without treatment measured in loop of pH 7-4-7-10-7

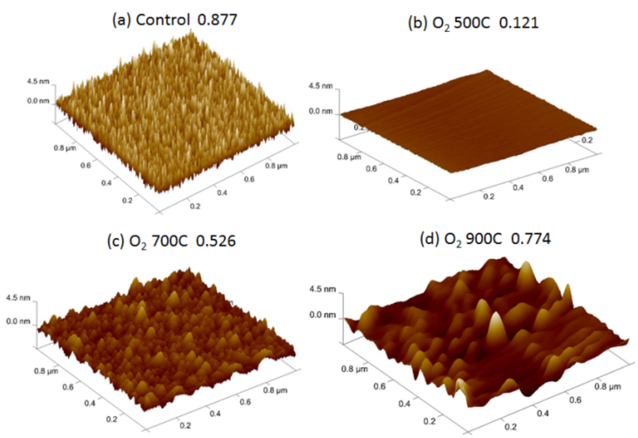

Fig. 7 Surface roughness of NbO_x-LAPS with different RTA treatment by AFM analysis.