Fabrication of a Hydrogenated a-Si Photodiode

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Abstract—A photodiode capable of obtaining a sufficient photo/ dark current ratio at both a forward bias state and a reverse bias state is proposed. The photodiode includes a glass substrate, an aluminum film formed as a lower electrode over the glass substrate, an alumina film formed as a schottky barrier over the aluminum film, a hydrogenated amorphous silicon film formed as a photo conduction layer over a portion of the alumina film, and a transparent conduction film formed as an upper electrode over the hydro-generated amorphous silicon film. Growth of high quality alumina(Al_2O_3) film using anodizing technology is proposed and analyzed by experiment. We have obtained the film with a superior characteristics

Index Terms—hydrogenated Amorphous Silicon Film, Photodiode.

I. INTRODUCTION

The proposed idea in this paper relates to photodiode, and more particularly to a photodiode exhibiting an increased on/off current ratio and a method for fabricating the same. Photodiodes are used for contract image sensors and barcode readers. For fabricating the photodiode as shown in Fig.3, a chromium film is deposited in a vacuum over a glass substrate. The chromium film is patterned by use of that wet etching process to form a lower electrode. Therefore, a hydrogenated amorphous silicon film is deposited to a thickness of 1m over the entire exposed surface of the resulting structure. Over the a-Si:H film, another chromium film is deposited. Subsequently, the chromium film is partially etched. Using the etched chromium film as a mask, the a-Si:H film is patterned by use of the reactive ion etching(RIE) process. Photodiodes utilized in facsimiles for sensing light reflected from a document or other objects and recognizing characteristics and letters. The accurate control for dark current is very important for gray scale level designation. Where the level of dark current is imperfectly determined, the sensing operation is inaccurately achieved. A plurality of photodiodes are used for a large document including a white part at one portion and a black part at the other portion, the characteristics of the photodiodes should be uniform. For obtaining the accuracy in the sensing operation and the uniformity in device characteristic, a material exhibiting an appropriate energy band gap should be used. Furthermore, such a material exhibiting the appropriate energy band gap must be able to maintain the uniformity in device characteristic and control the dark current. On the other hand, where the energy band gap is too large, it is impossible to accomplish the sensing function because all signals generated are detected as dark current. Therefore, a good characteristic can be obtained in photodiodes. A lot of photo current can flow by controlling a flow of dark current and we can obtain a high I_{photo}/I_{dark} ratio.

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II. AL_2O_3 FORORMATION BY ANODIZING METHOD

To form an alumina, we have experimented with a three electrolyte by choosing succinic acid, ammonium tartrate and boric acid when Al is anodizing. We have tested by changing a condition of currents of 30mA, 60mA, and 90mA voltages of 60V, 120V and 180V electrolyte, respectively. results have shown that the difference of alumina thickness is small in electrolyte conditions and characteristics of breakdown voltage have a much differences. These results mean that the characteristics of alumina film can vary by sorts of electrolyte.

We cannot measure breakdown voltage because it is very porous in case of boric acid. In case of ammonium, its film is more sensitive, but breakdown voltage is small compared to succinic acid. Therefore, we have experimented with succinic acid in TFT(Thin Film Transistor) and photo diode device.

TABLE I Condition of Alumina formation (Anode Oxidation)

Num	Electrolyte	Concentration(g/l)	Volts(V)	Current(A)
1	Succinic acid	2.3	5	20
2	Succinic acid	2.3	17	100
3	Succinic acid	2.3	30	180
4	Ammonium Tartrate	4.6	5	100
5	Ammonium Tartrate	4.6	17	180
6	Ammonium Tartrate	4.6	30	20
7	Boric acid	19.2	10	60

In this paper, we have measured breakdown characteristics of two layer film of breakdown voltage and Al_2O_3/SiN(1000) of alumina film formed under condition of succinic acid and ammonium tartrate as electrolyte, respectively. We can estimate that succinic acid is superior to ammonium, the breakdown voltage of alumina is 6.7MV/cm. Table 1 shows that parameters for forming alumina in experiment. Figure 1 shows the change of thickness of Al_2O_3 film by anodizing watts. Figure 2 shows breakdown voltage of Al_2O_3 film.

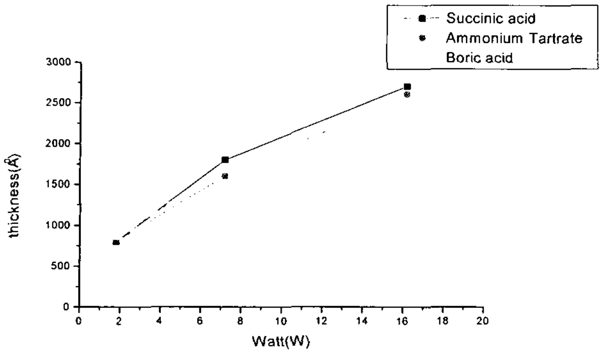

Fig. 1 Change of thickness of Al_2O_3 film by anodizing watts

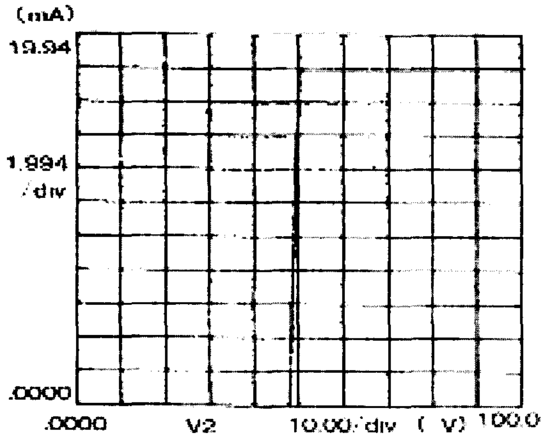

Fig. 2 Breakdown voltage of Al_2O_3 film

III. PHOTODIODE HAVING A BARRIER WITH AL_2O_3

Conventional amorphous silicon photodiode uses a schottky effect with Cr/a-Si:H/ITO structure. Cr and a-Si:H have a quasi-schottky characteristics and have a barrier height around 0.55eV, a-Si:H and ITO have a characteristics with ~0.93eV barrier height. Because stoichiometry is not fully controlled by deposition of ITO and process, schottky effect is not formed sufficiently in surface of amorphous, characteristics of its device show a n unstable state. Therefore, many researcher have tried to accomplish to have a stable schottky characteristics in ITO and a-Si:H. Some researchers focus on restriction of dark current by inserting an insulator layer near interface of ITO and a-Si:H[1,2]. When insulator layer is thick, the flow of dark current restricted, we have to grow a film which photo current can tunnel. Shallow insulator formation of a hundred by using this method cannot easily make a film without pin-hole, this method is not realized yet.

We have proposed new idea and structure and these methods can restrict dark current using energy band and photo current can pass randomly. We have realized that forms a insulator between electrode Cr in opposite of ITO and a-Si:H in active layer, we can achieve a good result above mentioned without having a shallow thickness of insulator[3,4]. To get a good insulator, we choose anodizing method and grow Al_2O_3 by anodizing with beneath electrode of Al. This method can control easily adjustment of thickness and confirm the realization of breakdown perfect. The experimental process is as follows.

First, glass substrate is cleaned, Al is deposited over glass substrate, the processes are tested under several conditions by anodizing with succinic acid. Second, Al and Al_2O_3 are patterned and deposited intrinsic a-Si:H with a thickness of 1m by use of the PECVD process, after deposition, ITO is deposited with thickness of 1500 Å by use of magnetron sputter equipment. Third, ITO is patterned with RIE process, by using pattern in nature, a-Si:H conducts RIE process. Al_2O_3 should be patterned to make an Al electrode. To reduce a damage of RIE, we have measured an electrode after annealing in air condition of 200~250℃ during 30 minute through 1hour.

Figure 5 shows the energy band diagram of ITO/a-Si:H/Cr structure. Figure 6 shows the energy band diagram of Al/Al_2O_3/i-a-Si:H/ITO structure in forward and reverse bias condition. In forward bias, Cr and a-Si:H show quasi-schottky contact. They form lots of dark current because dark current is not controlled properly. Therefore, photo current flows a lot without any barrier [5,6]. By using forward bias, we cannot obtain a higher light/dark current ratio. In reverse bias, ITO and have a schottky characteristics. A lot of light currents flow, dark current is restricted by this barrier. Then, we can obtain a higher light/dark current ratio. But, we have a trouble in making schottky barrier because of an unstable interface between ITO and a-Si:H,in particular, ITO stoichiometry [7]. Table shows the characteristics of photodiode using Al_2O_3. Figure 3 shows the process flow and structure of photodiode with barrier alumina. Figure 4 shows the photo/dark current of Al/Al_2O_3/a-Si:H/ITO structure.

Table II Characteristics of photodiode using Al_2O_3

Num.	Voltage (Volts)	Thickness (Å)	Forward bias	Reverse bias
			I_{on}/I_{off}	I_{on}/I_{off}
1	5	75	2×10^3	6×10^3
2	10	150	8.9×10^2	1.2×10^4
3	17	255	6.3×10^2	6×10^3
4	20	300	3.8×10^2	3×10^3
5	23	340	1×10^2	1.2×10^4
6	30	450	1.3×10^2	1×10^4

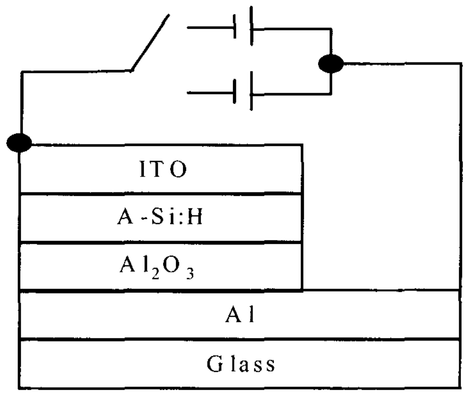

Fig. 3 Structure of photodiode with barrier alumina

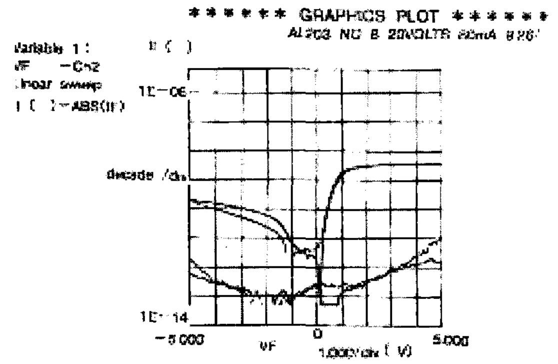

Fig. 4 Photo/dark current of Al/Al_2O_3/a-Si:H/ITO structure

IV. ANALYSIS OF PHOTO/DARK CURRENT OF PHOTODIODE WITH AL_2O_3/A-SI:H/ITO STRUCTURE

A. "-" in Al and "+" in ITO : in forward bias

In dark current, Al_2O_3 takes a play in potential barrier. It is restricted at its maximum and has a value below 10^{-12}A. In photo current, its barrier is changed according to thickness of Al_2O_3. That is to say, the shallower thickness of Al_2O_3 is formed, the higher current flows. As the thickness is thick, the current flows small. From the band diagram as shown in Figure 4, we can estimated that generated photon is attracted by injected bias, electrons move toward ITO, holes move toward Al direction. The barrier of Al_2O_3 does not affected in flow of electron, the flow of hole is affected by barrier of Al_2O_3. The tunneling effect occurred when barrier thickness of Al_2O_3 is below in any critical value. In case of charge generated by phonon, electron can move easily. But hole is very sensitive to thickness of Al_2O_3 and gives an effect of flow. the phenomena, we can estimate that the generation of photon in a-Si:H is restricted.

The flow of hole is blocked and photon generated in a-Si:H can emit outside as soon as electron is generated. But hole is accumulated to compensate and electron should be injected in alumina. This injected electron have to operate a dual tunneling with a schottky barrier of Al_2O_3 and Al/a-Si:H. As the thickness of Al_2O_3 goes thin, injection of electron increase and current increases. We can estimate that photon current in forward bias is sensitive and changes in proportion to thickness of Al_2O_3 film.

B. "+" in Al and "-" in ITO : in reverse bias

In the case of photon current at below thickness of critical value, Al_2O_3 and schottky barrier cannot effect and have a current a lot. But, in dark current, Al_2O_3 is serves as barrier and restricted. If thickness of Al_2O_3 is thinner, tunneling effect is generated by biased voltage and dark current increase. From the point of view, we can obtain a higher photon/dark current ratio with around 1000 thickness after anodizing Al_2O_3. In the case of dark current is difficult to tunnel the Al_2O_3 plate. In photo current, the generated photo carriers have an effect on increasing the fermi level of a-Si:H in interface between a-Si:H and Al_2O_3. We can estimate that this makes a tunneling effect easily. Figure 5 shows that Energy band diagram of Al/Al_2O_3/i-a-Si:H/ITO structure. Figure 6 shows that the Characteristics of photo/dark current by thickness of /Al_2O_3 with Al/Al_2O_3/a-Si:H/ITO structure

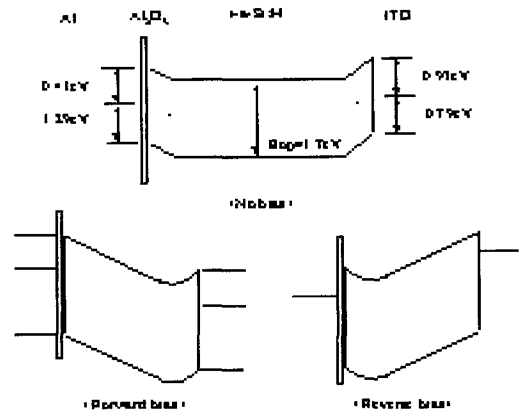

Fig. 5 Energy band diagram of Al/Al_2O_3/i-a-Si:H/ITO structure

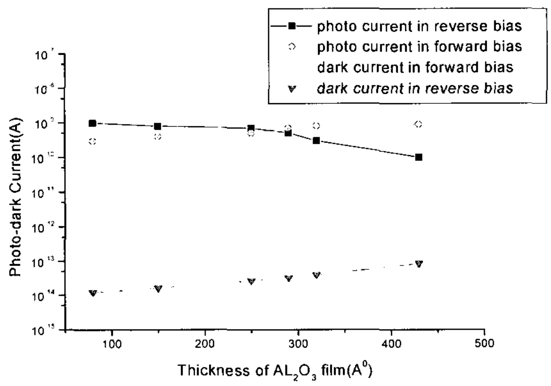

Fig. 6 Characteristics of photo/dark current by thickness of /Al_2O_3 with Al/Al_2O_3/a-Si:H/ITO structure

V. CONCLUSION

The method to gain growth of high quality Al_2O_3 film using anodizing technology and new etching technique is proposed. From the experimental result, the photo current of photon diode is large when the applied voltage is low. On the contrary, photo current is low when the applied voltage is high. Dark current is very small about 10^{-12}A. These phenomena have shown that the barrier in reverse bias in Al generates, photon current vary according to thickness of Al_2O_3 film. At the bias of "+" in Al and "-" in ITO, the photon current is generated as constant about $5x10^{-9}$A. These phenomena show that thickness of Al_2O_3 does not effect. Contrary to conventional method, the proposed method makes a barrier height in reverse side of ITO. This approach can remove the problem of the interface of ITO. Therefore, we can estimate that the proper shallow thickness of barrier height has a superior characteristics from the experimental results.

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