DESIGN AND FABRICATION OF A PN JUNCTION PHOTODIODE ARRAY

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ABSTRACT

An array of photodiodes consisting of various areas and/or metallization schemes were fabricated for use in a photodiode array. The two gate metals used were Aluminum and Aluminum/Ytterbium. The standard RIT PMOS process was modified to obtain a shallow junction depth for the photodiode. All the diodes generated a photocurrent when illuminated, but the Aluminum metal scheme produced better results due to higher open circuit voltages and short circuit currents. The fill factor was also much better on these diodes.

INTRODUCTION

A photodiode is one of the most fundamental methods of converting an optical signal into an electrical signal. When the photodiode is not illuminated it acts similar to a pn junction diode. However, when illuminated the photodiode it behaves quite differently from a normal diode illustrated in Figure 1. The illumination generates electron-hole pairs, which cause current to flow through the device. The most important factors to look for in a photodiode are the open circuit voltage which is the voltage measure across the diode when current flow is zero, the short circuit current which is the current measured when the voltage drop across the diode is zero, the current density which normalizes photocurrent to device area, and the fill factor which is the ratio of actual maximum power obtainable from the cell to the theoretical maximum (Voc x Isc).

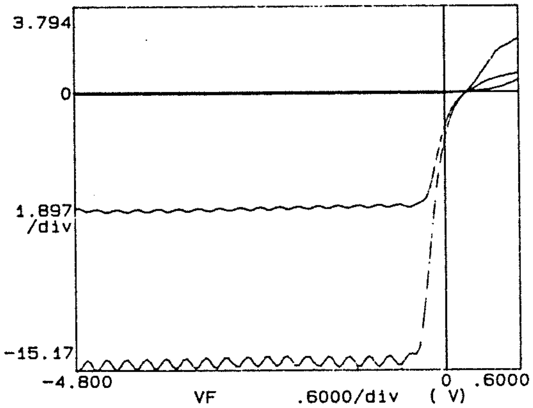

Figure 1: Theoretical Photodiode Curve

Discrete photodiodes may be employed to form an array of sensors. An example of this is shown in Figure 2. This circuit has two basic building blocks, the support circuitry and the photodiodes. The support circuitry consists of three clocked D flip flops cascaded together, which results in a shift register. The clock only allows an output on the flip flop when its input is high. The output of each flip flop goes to the gate of a pass transistor, which in turn connects the photodiode to the current-voltage amplifier. The pass transistor prevents more than one photodiode from being sensed at a time. To receive a reading at the output, an input pulse is placed on the first flip flop. The pulse is clocked through each flip flop consecutively connecting one photodiode at a time to the output pad. This can then be used to measure the spacial intensity of a light beam. For a more specific explanation of the logic see Reference 2.

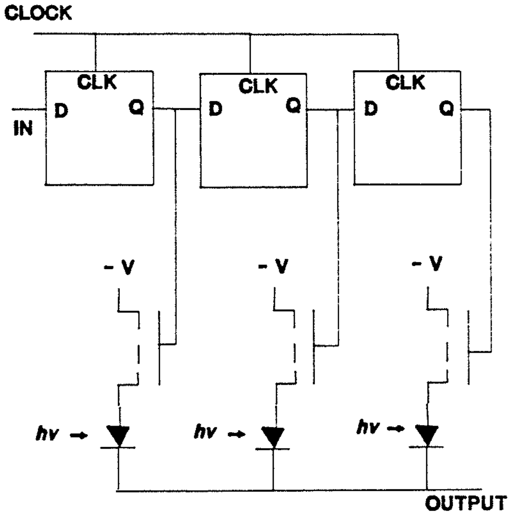

Figure 2: Photodiode Array [1]

This project involved the fabrication of a pn junction photodiode array using the standard RIT PMOS process. A few alterations were required on the process to achieve working photodiodes. These changes consisted of the addition of one masking layer to define the photosensitive areas, where the p-type diffusion had to be to less than 1 micron. The mask will be added after the normal drain-source diffusion mask and will not require a growth of another masking oxide. This is accomplished by performing the drain-source diffusion using a spin on source, which results in a Borosilicate glass being formed. This will be etched back and the wafers will then undergo the drain-source drive-in step, which regrows the field oxide. Now, the additional mask is employed to open up windows for the photodiode areas. A solid source predeposit will be done to achieve the desired shallow junction depth in this region. From this point on the process returns to the standard RIT PMOS process. The thin gate oxide grown after the last diffusion step will cover the photosensitive areas, as well as, the gate areas. This oxide will act as an antireflective coating to the photosensitive areas. The thickness of the oxide desired is between 1000 and 1200 Angstroms. This thickness will minimize the reflections from the surface. A cross section of the final PMOS/pn junction photodiode array can be seen in Figure 3.

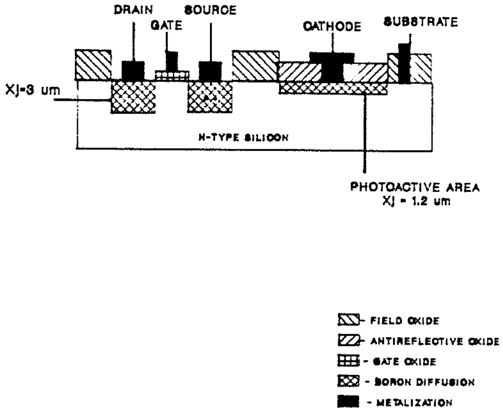

Figure 3: Cross Section of the Final Photodiode array

One other area of concern in the process involves the metal. The photodiode requires an ohmic contact to the p-type diffusion and n-type substrate, and normally one metal will not form both contacts. Aluminum is a p-type dopant and will therefore produce a good ohmic contact to the p-silicon, while a low work function metal, such as Ytterbium will form an ohmic contact to the n-silicon substrate. The Ytterbium should etch just fine in the Aluminum etch, so this part of the process doesn't need to be altered.

Several different photodiodes were designed and tested prior to building the actual photodiode array. The purpose of this was to determine the best diode size and metal grid pattern. The amount of metal on the photosensitive area will determine the amount of area which sees the light. Ideally, the metal coverage should be kept to a minimum, something on the order of 10 to 20 percent of the total area [3,4]. A contact grid surrounds each photodiode, so as to lower the resistance to the substrate. A layout of the photodiodes and the photodiode array can be seen in Appendix 1.

EXPERIMENT

The process began by taking several n-type, 100, 5-8 ohm/cm wafer and growing a field oxide of approximately 4000 Angstroms. The wafers then underwent the photolithographic steps for the drain-source. A spin on dopant, Allied B150, was used to complete the drain-source diffusion. The doped glass was etched back and 3500 Angstroms of field oxide was regrown, while the dopant was being driven in. Photodiode diffusion areas were lithographically defined and a Carborundum BN975 solid source predeposit was done. The doped glass was then stripped back and the photolithography for the gate regions was completed. The gate oxide was grown, giving 400 - 500 Angstroms of oxide over the gate regions and 1000 - 1200 Angstroms of oxide over the photodiode areas. This step also served to drive in the photodiode predeposit. The contact cuts were lithographically defined and the Aluminum was deposited on to the wafers. Finally, the Aluminum was patterned and the wafers were sintered and tested. The process used to fabricate just the photodiodes was exactly the same as that used for the photodiode array, except the drain-source diffusion and drive in were omitted.

For a complete listing of all process times, temperatures, and other assorted values see Appendix 2.

RESULTS/DISCUSSION

Each photodiode was tested using an HP4145A parameter analyzer, a microscope light, and another external light source. The microscope light had an irradiance of 1.5 mW/cm2 and the microscope light coupled with the other external light source had a combined irradiance of approximately 8 mW/cm2. The results found can be seen in Table 1 with a listing of the actual plots from the parameter analyzer located in Appendix 3.

DIODE	DIFFUSED AREA	METAL COVERAGE	Al CURRENT DENSITY	Yb CURRENT DENSITY
1	1.0 cm**2	15.8 %	- 113	- 168
2	1.0 cm**2	8.8 %	- 107	- 96
3	0.6 cm**2	14.7 %	- 63	- 213.3
4	0.6 cm**2	10.5 %	- 102	- 200
5	0.6 cm**2	6.3 %	- 78.3	- 256.7
6	.36 cm**2	12.5 %	- 136	- 144.4
7	.36 cm**2	27.5 %	- 78	- 461

Table 1: Photodiode current densities in uA/cm2

Both the Ytterbium coated wafers and the standard Aluminum wafers produced working photodiodes. The Ytterbium wafers showed a much greater leakage current than the Aluminum wafers and photocurrent densities were less repeatable. The Ytterbium had larger photogenerated current densities then their Aluminum counterparts, but their short circuit current densities were drastically reduced. Since the Aluminum wafers resulted in acceptable responses the Ytterbium process was eliminated.

Now that the metalization process was determined the best functioning photodiode design was evaluated. This was done by choosing the diode with the least amount of leakage current and the greatest amount of current density. Another criteria was that the photocurrent must be repeatable across the wafer. The diode chosen was diode 6, which has an area of 0.36 um2 and a metal coverage of 12.5%. The photocurrent obtained from this diode was approximately -49 uA, which is equivalent to a current density of 136 uA/cm2. This diode was now placed into the photodiode array.

CONCLUSIONS

Working photodiodes were obtain with the best results occurring for an area of 0.36 cm2, a 12.5% metal coverage,a current density of 136 uA/cm2, and using only the standard Aluminum metalization process.

For additional work on this project, I would recommend that the Ytterbium process be investigated further. Ytterbium, if used correctly, should produce a more efficient photodiode due to the low work function of the metal. One could also investigate and optimize the diffusion step used to obtain the shallow junction depth. Finally, I would recommend that the photodiode array should be fabricated and tested to see if the design works.

ACKNOWLEDGMENTS

Joseph DeSantis

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REFERENCES

[1] Mark Bernhardt, Senior Project, Rochester Institute of Technology, 1986

[2] Herman Lam and John O'Malley, FUNDAMENTALS OF COMPUTER ENGINEERING Logic Design and Microprocessors, (1988 by John Wiley and Sons, Inc.)

[3] Nick Holonyak Jr., SOLID STATE ELECTRONIC DEVICES, (1980 by Prentice-Hall Inc. of Englewood Cliffs, NJ)

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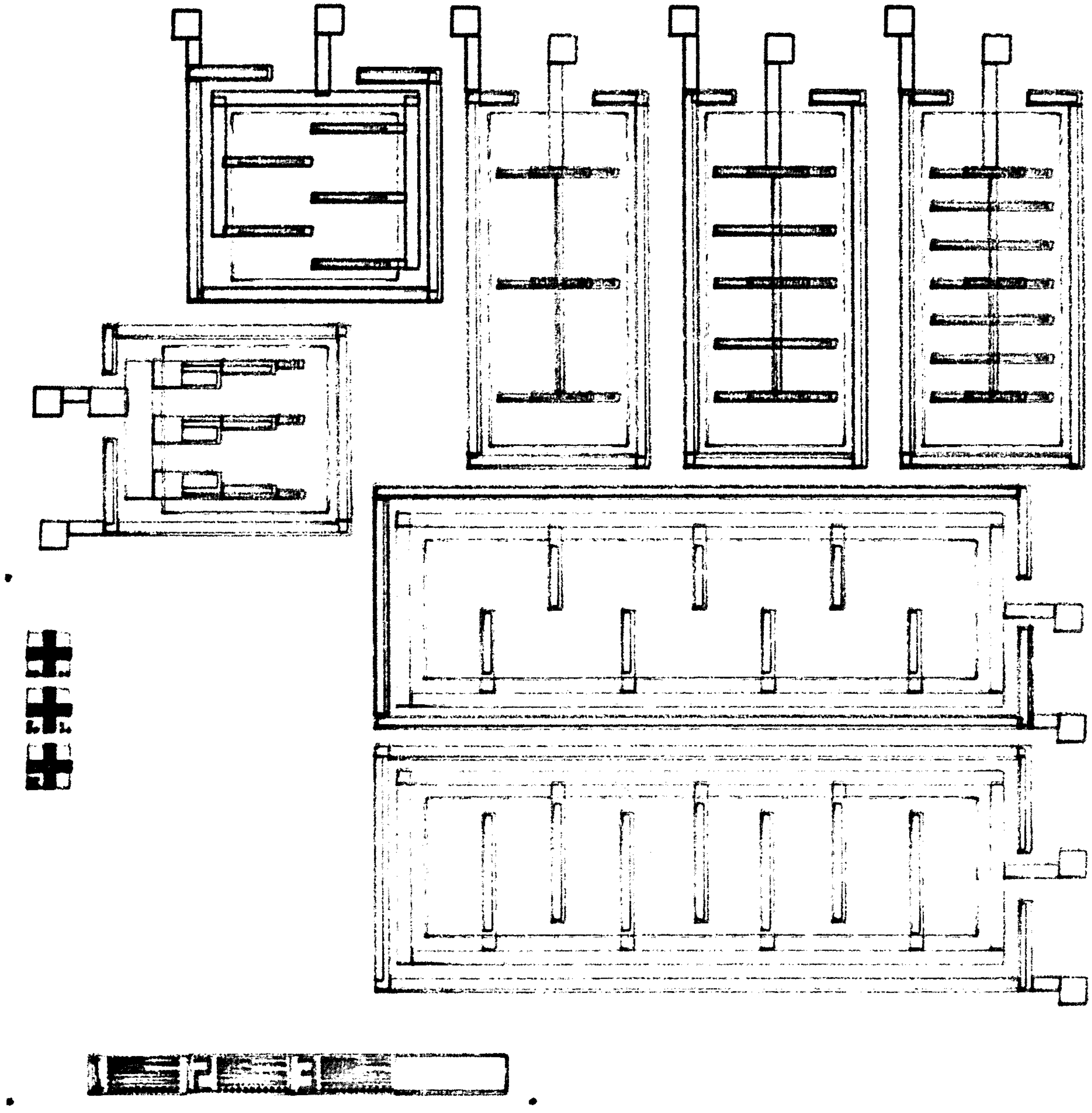
APPENDIX I

Photodiode test chip



APPENDIX I

Photodiode array chip