Investigation of microplasma cells fabricated on silicon wafer

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Abstract— The objective of this project was to investigate the possibility of producing array of microplasma, having aluminum and silicon electrodes, and oxide as a dielectric with cavity size as large as 30x30 μm^2. One of the potential applications among many was to use such device as a photodector. A new class of photodectors, hybrid semiconductor-microplasma devices, to exhibit photoresponsivities in the visible and near infrared that are more than an order of magnitude larger than those typical of semiconductor avalanche photodiodes [1]. After fabrication processing, the route causes of failure were determined. Processing problems were diagnosed and process evaluation test structures characterized using optical microscope, and scanning electron microscopy (SEM). Oxide insulation between the metal layers (Aluminum) was tested using a multimeter. Continuity tests revealed a short between the metal electrodes. The application of SEM in this failure analysis of a finished device shows aluminum stringers left in the cavities. This was the confirmation of a potential short previously diagnosed with the multimeter test.

***Index Terms*—Microcavity plasma device (MPD), microplasma, plasma, photodetector.**

I. Introduction

Techniques developed originally for semiconductor processing, offer exciting opportunity to fabricate devices capable of producing weakly ionized microplasmas [1]. The reduction of the plasma typical dimensions down to the micrometer range or less is expected to bring previously unobserved physical phenomena to the fore as well as to offer new device applications [2]. Research activities along this direction have been increasing on a worldwide scale especially in the US and Japan since the late 1990s [1,2]. These researches are pursuing two main goals: (1) to investigate the physics of weakly ionized plasmas confined to sub-millimeter dimensions and (2) to develop materials and structure platforms that allow microplasma to be integrated with electronic and photonic components, as well as to be mass produced economically. In this paper, microplasmas design, fabrication and testing was investigating

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II. Theory

A. What is plasma?

Plasma is often referred to a fourth state of matter in addition to solid, liquid, and gas. In plasmas the degree of ionization is high and therefore high densities of ions and electrons are found. Plasma can conduct electricity and interact strongly with electric and magnetic fields.

Specifically, plasma is ionized gas. That is, gas that has been given energy by being stripped of electrons. Such ionized gas is the most abundant observable form of matter in the universe, being a main ingredient in stars and nebulas. It is also what the main part of a flat panel displays called "plasmas". Why? Because when you apply an electromagnetic field to the pixel, plasma glows, making for a high contrast, vibrant TV screen, computer monitor, or digital sign [3].

B. Generation of Microplasma

1) Generation method:

To create plasma, energy must be supplied to gas. This energy can be provided in various ways, including heat, or electromagnetic (EM) field.

There are many ways to generate plasmas of small scales. Plasma generation methods are classified on the basis of the frequency of the power sources; the range spreads from DC to GHz. In DC operation, the most popularly used design is the hollow cathode (HC) type, which has been studied by the Schoenbach's group recently from miniaturized structures and integrated assemblies [7,8].

In the pulse discharge mode, the dielectric barrier discharge (DBD) configuration is often used, in which both or at least one of the electrodes is covered with an insulating material, as shown in Fig. 1 [1]. An example of this DBD scheme is seen in the unit cell of current commercial plasma display panel (PDP) show in Fig. 1 as a coplanar type (a) [10]. The structure (b) is called the counter-electrode type, which was used in the earlier phase of the PDP research. Recently, its modified structure of a horizontal type (b') has become manufacturable [11]. The structure (c) can be called a coaxial type, in which the discharge is sustained between the upper and lower electrode [12], while the type (c') is a version with an auxiliary mesh electrode. The type (b') and (c) or (c') may be preferable for material processing purposes since the source gas be fed vertically to the electrode plane through the hole.

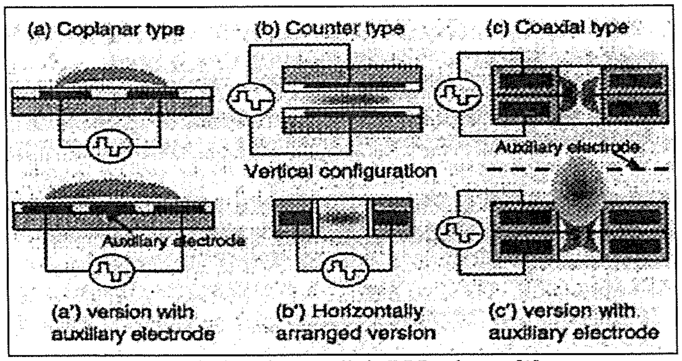


Figure 1: Examples of microplasma cells in DBD schemes [1]

2) Media for microplasma

High-pressure gases are mostly used as media for the generation of microplasma, where the design of the gas flow is an important issue for realizing the nonequilibrium state under controlled conditions. The additional gas flow driven by the ion drag force flowing toward the cathode may have a large influence as the operating pressure increases [1].

C. Characteristics of Microplasma

In general, plasmas have reactive, radioactive, and conductive properties. When these properties are combined with the characteristics of microplasma such as plasmas (electrons) density n_e, residence time of electrons τ_d and temperature, there are a variety of possibilities for the application of microplasmas.

III. SILICON MICROPLASMA PHOTODETECTORS

A. Mask design

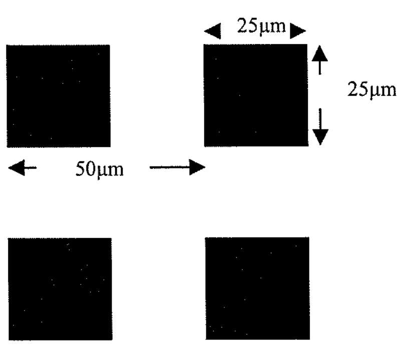


Figure 2: Layout of oxide mask (lithography 1)

The masks design specifications are summarized in Table 1. There were two masks, oxide and metal. The only difference between the mask was the size of the dark boxes, 25x25µm^2 for oxide (Figure 2) and metal 30x30µm^2.

Cell Layout size	9980µm
Plate size	5"x5"x0.0090"
Array	Array with 10 rows and 10 columns
Field type	Dark field
Orientation	Mirror 90

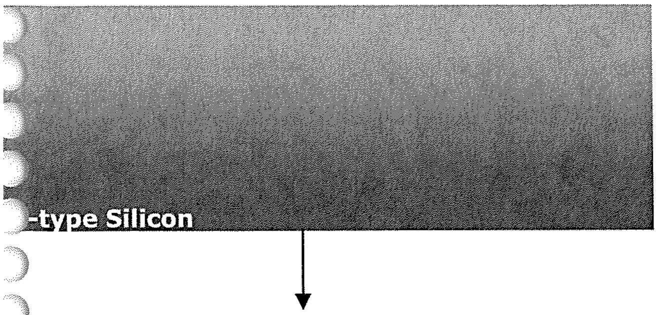
Table 1: Mask Specifications

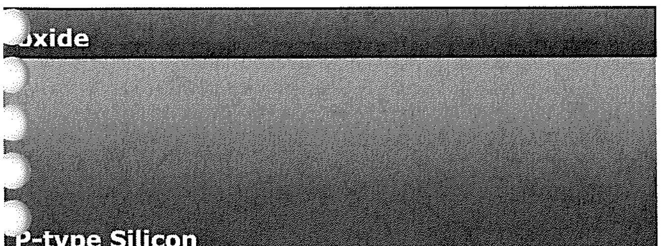
B. Process Details

#	STEP NAME	Area	RIT Tools	RECIPE
	Aquire Wafers			
1	Scribe	Metrology		
2	ResMap	Metrology	CDE Res Map	4_inch_Rs_25pt 4_inch_Rs_5pt
3	RCA Clean (#1)	Wet	Wet Bench	SMFL Standard process
4	Oxide Growth (Dielectric)	Thermal	BRUCE 01 TUBE 01	Recipe:440 1100C Wet Ox - 35hrs soak time
5	Litho level 1: Cavity creation	Litho	Sus MA 150 Aligner	SVG track Standard Coat/Develop Recipe
6	Oxide Etch	Wet	BOE 5.2:1	40 min
7	Resist Strip	Dry Etch	Branson L3200 Asher	Branson Asher 4in normal or hard ash
8	Cavity Etch	Wet Etch	Dr. Fuller: 20 wt% KOH	Dr. Fuller KOH set up: 75C, rate at 30 µm/hr (it would take about 15 min to get down to 10 µm deep)
9	Decontamination	Wet	Need to Contact Sean	
14	Al Deposition(Front)	Thermal	CVC601 - Sputter Al	
15	Al Deposition(Back)	Thermal	CVC601 - Sputter Al	
16	Litho level 2: (Metal)	Litho	Sus MA 150 Aligner	SVG track Standard Coat/Develop Recipe
17	Metal Etch	Etch	LAM 4600 Metal Etch	LAM 4600
18	Resist Strip	Dry Etch	Branson L3200 Asher	Branson Asher 4in normal or hard ash
19	Sinter	Thermal	BRUCE TUBE 02	BRUCE TUBE 02 425C for 20 minutes in H2/N2
20	Dicing	Packaging	KS780 Dicing Saw	
21	Test			

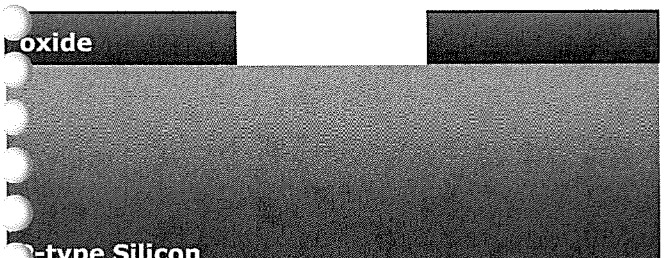
Table 2: Process Details

The process details are tabularized in Table 2.

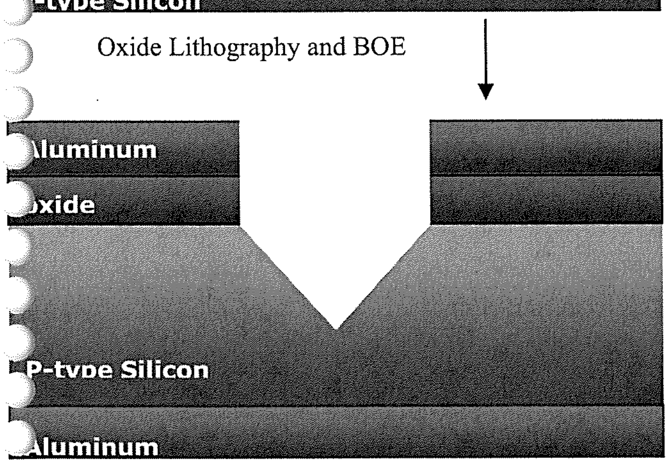




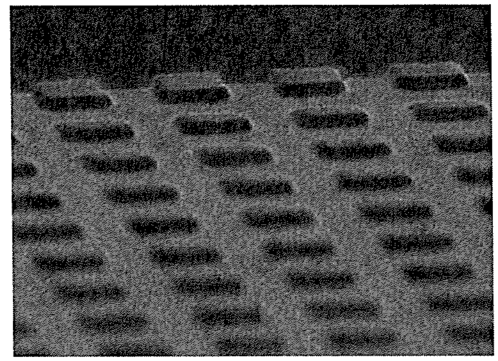
After oxide growth



Oxide Lithography and BOE



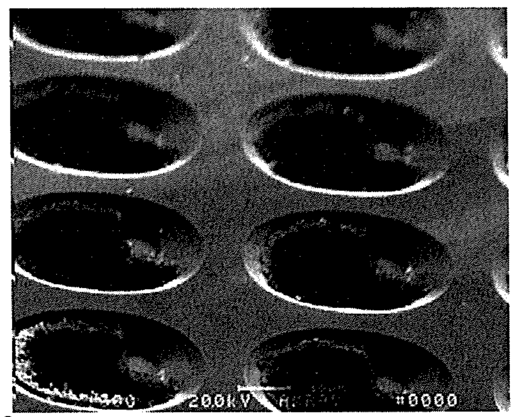
Aluminum sputtering follows by its dry etch, and back side Al



IV. Results and Analysis

Figure 3. SEM picture of microplasma array

Figure 3 shows SEM picture of a segment of the microplasma array. The device pitch for this array is 50μm with a



30x30μm^2 opening (Oxide and Al. without Si Etch)

Figure 4. SEM picture of cavities showing stringers caused by misalignment

Oxide insulation between the metal layers (Aluminum) was tested using a multimeter. Continuity tests revealed a short between the metal electrodes. The application of SEM in this failure analysis of a finished device (Figure 3, 4) shows aluminum stringers left in the cavities. This was the confirmation of a potential short previously diagnosed with the multimeter test.

On a working device one expects a capacitance, due to the electrode gap, to be in parallel with an oxide capacitance as illustrates in Figure 5. Contrarily the aluminum presence in the cavity resulted in a short of the cavity capacitance. Figure 6 shows equivalent circuit of the potential microplasma shorted by the aluminum presence in the cavity.

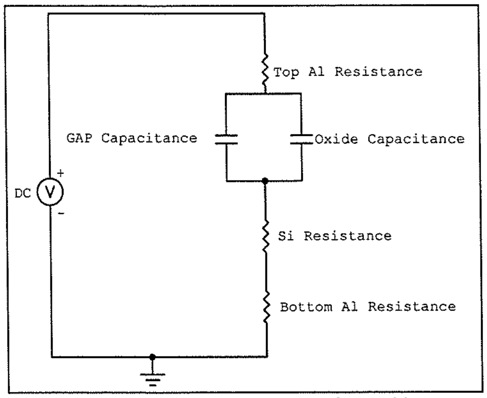


Figure 5. Equivalent circuit diagram of a working silicon microplasma cavity

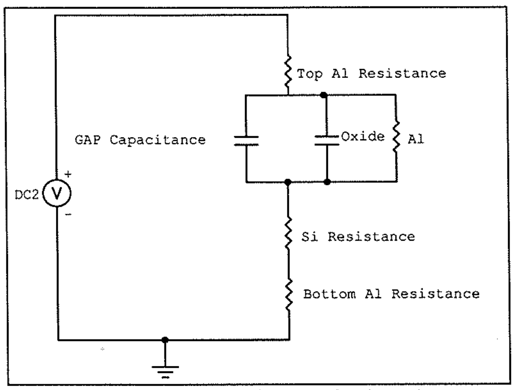


Figure 6. Equivalent circuit diagram of a shorted silicon microplasma cavity

V. CONCLUSION

In this project, the investigation of microplasma fabrication has been reviewed. Overall, it was found that changes needed to be made in the process flow as well as the mask design to successfully complete the device. Such changes include using thinner oxide, a self-aligned etch to reduce the oxide undercut. In addition a fairly visible alignment mark is needed on the mask to alleviate alignment with a dark field mask.

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