Design rules for Patterning in Deep Cavities Formed by TMAH-etching of Si

Lei Gu, Wim Wien, and Lis K. Nanver

***Abstract*— The exposure in deep cavities is investigated, including the influence of light scattering and reflection. Some design rules are given for making layouts and processing devices. Using of spray-coated negative resist is for the first time reported for application in deep TMAH-etched cavities. This allows for implementing acceptable metal strips in the cavity and alleviating the error coming from light reflection.**

Index Terms— **bulk silicon micromachined cavities, spray resist-coating, negative resist**

I. INTRODUCTION

Bulk micromachining of silicon with wet-chemical etchants such as TMAH is finding many uses in areas such as MEMS [1], integrated sensors/actuators [2, 3], and RF/microwave ICs [4]. For the latter, micromachining can give access to the back of the wafer, making it possible to, for example, more economically integrate large passive components, reduce interconnect resistance and improve device performance by reducing parasistics. The versatility with which the bulk micromachined structures can be integrated is considerably increased if the patterning of deposited dielectric and metallic layers can be performed reliably on the non-planar surfaces.

For RF/microwave applications, exact knowledge of the metal track area is important for predicting losses. For this purpose, design rules have been developed for patterning in through-wafer cavities of about 525 μm deep.

Until now, literatures seldom focus on the exposure into the deep cavity. Actually, there are two typical phenomena which will cause serious result during exposure into cavity, namely, light scattering and reflection. The first phenomenon is not a big trouble in planar surface process. The gap between the mask and photoresist layers is very small, only 2-5μm. Nevertheless, the gap for the exposure in deep cavity is much larger. Hereby, the actual pattern will always be distorted from desired one due to the light scattering. Generally, the influence of light scattering cannot be eliminated in the deep cavity exposure. Fortunately, pattern errors from scattering can be predicted and taken into account before designing the mask. The second one is light reflection. Normally, positive resist was sprayed to pattern contact windows in the bottom of cavities. Since most of regions are dark for the mask of contact holes, positive resist is a suitable choice in spite of the reflection of the light. However, for metallic layers that should be patterned in thin tracks, the cavity walls are largely not covered by resist and the patterning with positive resist is complicated by strong reflections of light from the walls. By using a negative resist this problem is alleviated and good results can be achieved.

In this paper, we demonstrate some test structures to give design rules, which can be used to optimize the mask layouts and processes. We also report for the first time on the use of spray-coated negative resist to form metal strips in deep TMAH-etched cavities.

II. EXPERIEMTN

A testing structure is designed to demonstrate the exposure in deep cavity, and the schematic process is shown in Fig.1.

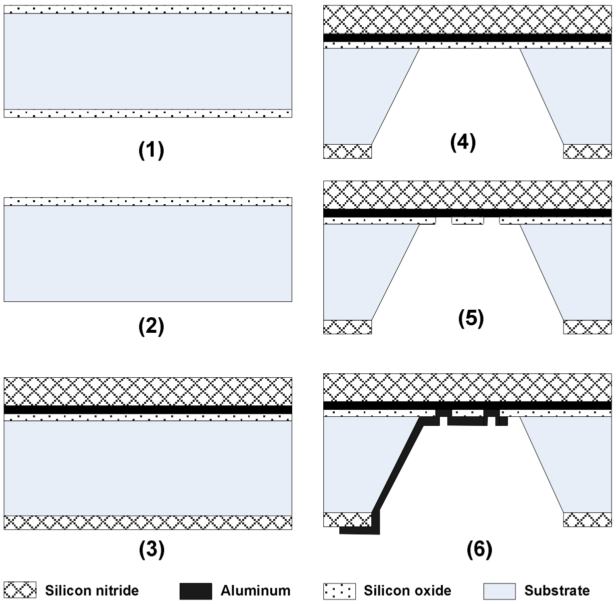

Fig.1 . The process flow for testing exposure into deep cavity.

(1) The process starts from p-type (100)-oriented 4 inch ordinary silicon wafers with a resisitivity of 1-10Ω·cm. The wafer surface is thermally oxidized with a thickness of 400nm, which is used to be a stop layer during TMAH etching and simulate buried oxide in SOI wafer.

(2) The frontside of the wafer is covered by a 1.4μm photoresist to protect the thermal oxide during HF etching. Then, the wafer is put into buffer HF solution to remove unprotected oxide on the backside.

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(3) Followed by sputtering 675-nm-thick aluminum on the frontside, 2μm silicon nitride is deposited with PECVD (Plasma Enhanced Chemical Vapor Deposition) technology. Another 1 μm silicon nitride is deposited on the backside as the hard mask during TMAH etching.

(4) After photoresist coating, exposure and developing on the backside, 1 μm silicon nitride is selectively removed by plasma etching. Since some pinholes exsit in the 1 μm silicon nitride, the wafer frontside is further protected by special Teflon single wafer holder. Then, using the 25% TMAH etch bath at 85 ^{o}C, the wafer is etched throughout the substrate and self-stopped on the 400nm-thick thermal oxide layer after 14 hours.

(5) The normal spin-coater cannot achieve a uniform photoresist layer into 535μm-deep cavity. By using an industrial EVG-101 spray-coating machine, 5μm-thick positive photoresist (AZ9260) is spray-coated on the surface of both the cavity bottom and sidewalls uniformly. With contact aligner, the pattern in the deep cavity is exposed by a longer exposure time of 15 second compared to normal one of 3 second. After developing, the thermal oxide on the bottom is patterned by dry etching.

(6) Finally, a 1.475 μm-thick Al is sputtered into the cavities. Based on the consideration of light reflection, a negative resist (AZ2070) is spray-coated on the cavity. The aluminum layer is patterned as connected strips from the frontside to the backside

III. CHARACTERIZATION AND DISCUSSION

The lateral dimensions of the TMAH-etch windows were designed from 1 mm×1 mm to 1.7 mm×2.4 mm. In the following sections, we will give some details about light scattering and reflection.

A. LIGHT SCATTERING

For the exposure into deep cavity, the light scattering is a big trouble, which is schematically shown in Fig. 2. The exposed region is a bigger than the size on the mask.

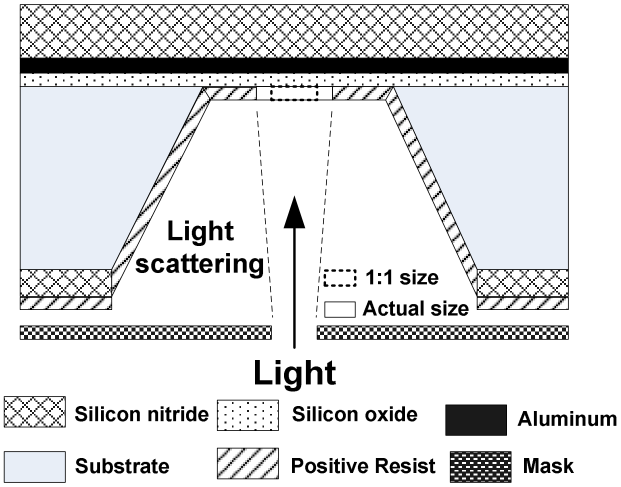

Fig. 2. The schematic drawing for explaining the light scattering.

Shown in Fig.3a, positive resisit is used to pattern contact windows on the bottom of the cavity. Depending on the cavity dimensions, the patterned window size is much larger than the on-mask dimensions due to the scattering of light within the cavity. Some rectangular and square layouts are design for testing. Since the light energy distribute on the exposure region is not uniform, the edge of the pattern is not regular. The final dimension of pattern is still depended on other factors, such as the time of exposure and developing. Different contact window sizes in the bottom of the cavity were patterned and the final window size could be normally enlarged by as much as 15 – 20μm in each direction.

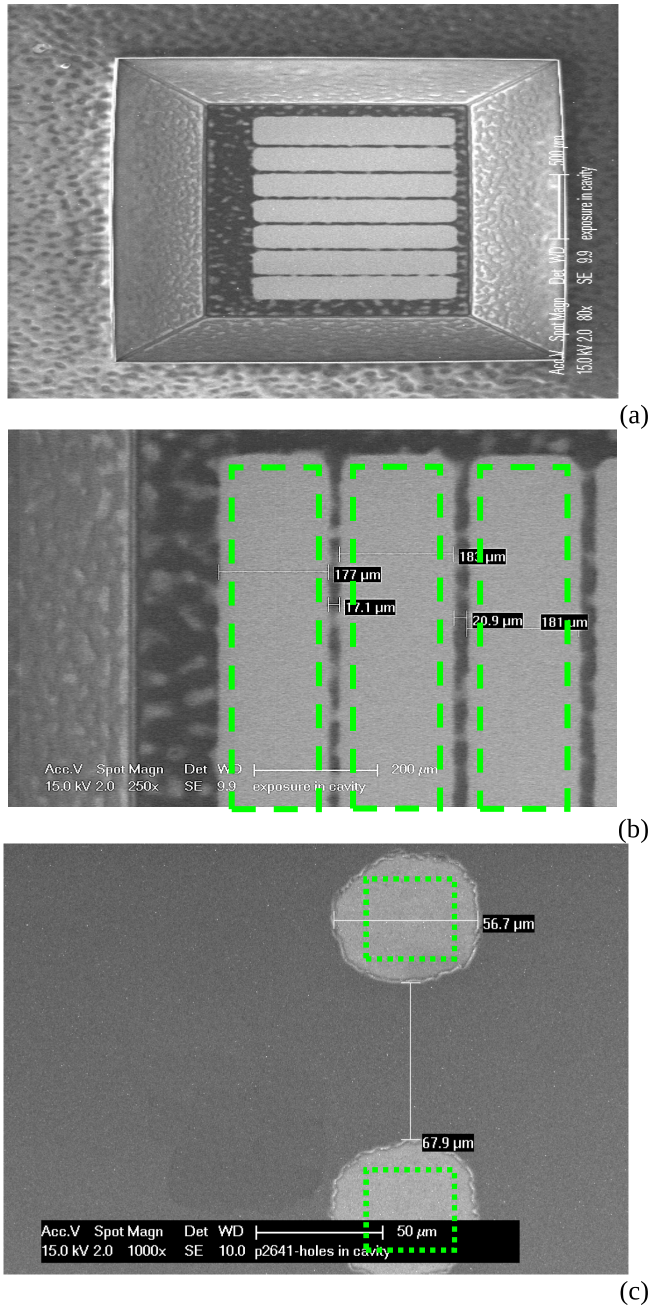

Fig.3. (a) SEM images of rectangular patterns on the bottom of the cavity. (b) A close-up view of strips in the cavity. (c) The circular patterns on the bottom, coming from the square windows on the mask (Green dash lines indicate the pattern on the mask)

B. LIGHT REFLECTION

The light reflection is much more complicated and destructive, especially when the surface of cavity is sputtered by metal. As shown in Fig.4 (a), the light coming from left side is reflected to the right side where the photoresist should have remained after developing. For metallic layers that should be patterned in thin tracks, the cavity walls are largely not covered by resist and the patterning with positive resist is distorted by strong reflections of light from the walls. The schematic and SEM pictures are shown in Fig. 4(b). These ghost images would bring unwanted result, such as disconnection or open circuit.

However, for the contact windows on the bottom of the cavity, most of region on the mask are dark. The effect of reflection can be neglected even the positive resist is used, as shown in Fig.3 (a) and (c).

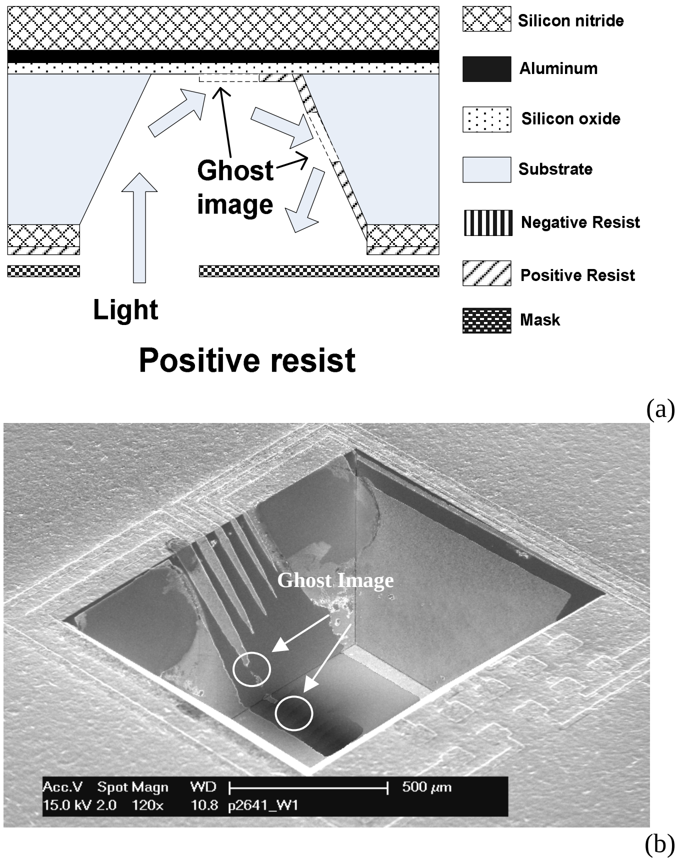

Fig. 4 (a) The schematic principle for light reflection, exposure with spraying positive resist. (b) The SEM image shows the result after developing and the ghost images.

Due to the property of negative resist, it will be a better alternative for forming metal strip on the bottom and sidewall. In this paper, a type of AZ2070 negative resist is firstly used to suppress the influence of light reflection. Schematic and SEM image are also shown in Fig.5 (a) and (b), respectively. Although a few ghost patterns are still appeared on unwanted regions, the light reflection can be distinctly depressed and complete metal strips are achieved.

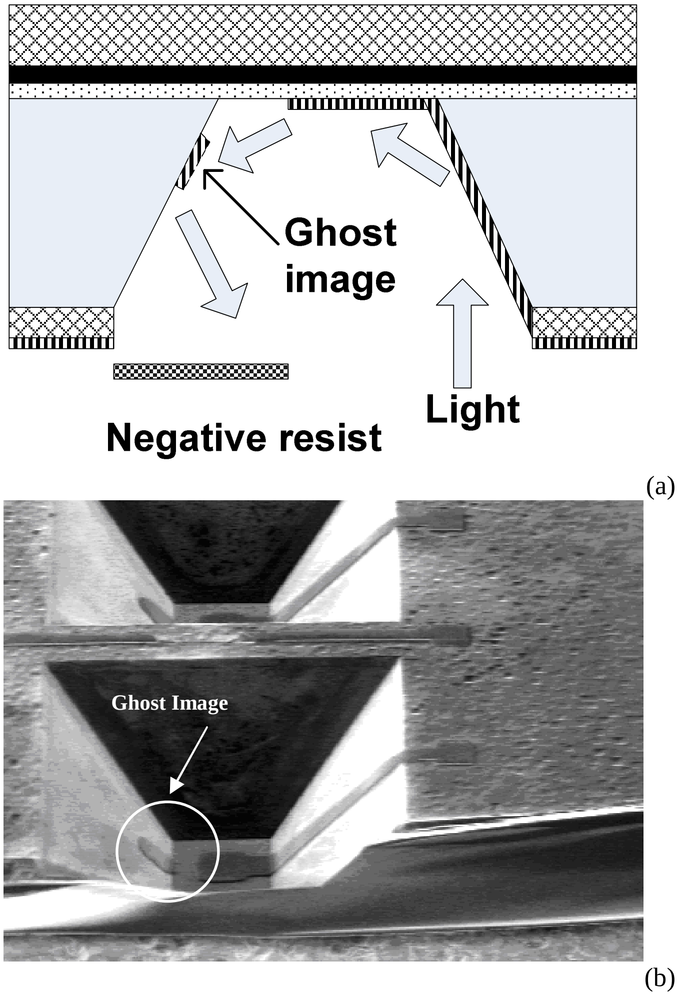

Fig. 5 (a) the schematic principle for light reflection, exposure with spraying negative resists. (b) The SEM image shows the result after developing and the ghost images.

Normally, the patterns on the bottom and sidewall are not very complicated. By careful design, these ghost patterns can be driven far away from the useful pattern, like the strip shown in Fig.5 (b).

For the same reason in previous section, the metal strips only required on the bottom can be implemented by negative resist without any ghost image.

IV. CONCLUSION

In this paper, we report for the first time on the use of spray-coated negative resist in deep TMAH-etched cavities to suppress the influence of light reflection. According to different applications, positive and negative resist have their respective merits. For example, positive resist is better to form contact windows in the cavity, which masks are largely dark. The negative one is suitable for implementing metal strips on the bottom and sidewall.

Except the light reflection, the light scattering is hard to be eliminated. During these experiments, different contact window sizes in the bottom of the cavity were enlarged by as much as 15 - 20µm in each direction. Fortunately, the pattern errors due to the light scattering can be predicted and taken into account before designing masks.

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