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Prevention of sidewall redeposition of etched byproducts in the dry Au etch process

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Abstract
In this paper we present a new technique of etching thin Au film in a dual frequency inductively coupled plasma (ICP) system on Si substrate to prevent the redeposition of etched Au particles over the sidewall of the masking material known as veils. First, the effect of the lithography step was investigated. Then the effects of etch chemistry and the process parameters on the redeposition of etched Au particles on the sidewall of the masking material were investigated. The redeposition effect was examined by depositing a thin Ti film over the masking material acting as a hard mask. The results showed that depositing a thin Ti film over the masking material prevents the formation of veils after etching Au in plasma environments for submicron size structures. Based on the results of this study, we propose a new technique that completely eliminates formation of veils after etching Au in plasma environments for submicron size structures.

(Some figures may appear in colour only in the online journal)

1. Introduction

Several materials can be used as a metallization layer in the fabrication of MEMS devices. Choice of the material is determined by considering the performance requirement of the device including electrical resistivity, adhesion characteristics, deposition conditions of the film and selectivity issues. Au offers several notable performance features like having a low resistivity, high chemical stability, high melting point and low surface work function which gives good ohmic contact with other metals [1]. Therefore it has been extensively used as a metallization layer in the fabrication of MEMS devices.

Thin film patterning methods fall into two categories; dry and wet etch chemistries. Dry etch chemistry becomes more important when the feature resolution is critical. Therefore, the most important advantage of etching Au in plasma environments is having less undercut compared to wet etch processes. Different masking materials including photoresists and hard masks using chlorine and fluorine containing etch chemistries have been reported for etching Au in plasma environments [2]. However, even etching Au in an ICP system operating at low pressure with ease control of bias voltage, redeposition of etched byproducts to the sidewall of the masking material, photoresist, cannot be completely eliminated by optimizing the process parameters [2, 3]. The sidewall redeposition problem during the Au etch process in plasma environments has been studied since the 1990s [4–7]. There exist two different approaches to eliminating this redeposition effect; preventing the sidewall redeposition of etched byproducts using different etch chemistries, etch process parameters and masking materials, or removal of the residues at the sidewalls using post cleaning processes [8–11]. Although this problem can be eliminated using different techniques, they may not always be applicable considering the process conditions.

Having a tapered profile for the masking material, photoresist, is one of the techniques that may eliminate this problem by enhancing the removal of the deposited byproducts on the sidewall of the masking material by resputtering them with the incoming ions during the etch process. However, making profile angle of the photoresist negative becomes difficult as the feature sizes get smaller.

It has also been reported that using a hard mask will also eliminate the redeposition effect with well optimized etch process parameters [5, 12]. However it is not always possible to use hard mask as an etch mask especially when you are concerned with the selectivity of the etch stop layer with the masking material while removing the masking material after etching is completed.

The main objective of this work is to present a technique that eliminates the formation of veils after etching Au in a plasma environment using photoresist as an etch mask even for nano-scaled feature sizes for the first time. First, the effect of the masking material, photoresist and its profile angle on the redeposition rate by keeping the etch process parameters constant were investigated. Then the etch process parameters were optimized to minimize the redeposition effect. Finally, the redeposition of the etched byproducts on the sidewall of the masking material by depositing a thin Ti film over the masking material that will act as a hard mask has been investigated.

2. Experimental details

For the investigation of the sidewall redeposition effect, 0.2 μm stress free Si_xN_y film deposited 6 inch Si wafers were used as a substrate. Si_xN_y film was deposited at 300 °C using a dual frequency, 13.56 MHz and 380 kHz, PECVD system followed by depositing a 10 nm Cr layer as an adhesion layer before depositing a 200 nm Au layer in a sputtering system. Plasma etching of Au thin film was performed using an STS Multiplex inductively coupled plasma etch system with a dual frequency RF generator. The first 13.56 Mhz RF generator connected to a coil is used to generate the plasma. The second 13.56 MHz generator is used to accelerate the ions to the wafer that is applied between the generated plasma and the platen electrode allowing independent control of the bias potential. The wafer temperature is maintained at a set point by transferring the heat from the cooled chuck to the wafer by applying pressurized helium to the back of the wafer and the wafer is mechanically clamped to the platen electrode. Finally, visual inspections were performed in an SEM imaging system after the etching process.

First, the profile angle of three different photoresists, Shipley S1805, S1813 and Ultra-i 123 08, were investigated. All photoresists were spun at 4000 rpm and soft baked at 115 °C for 1 min. Exposures of the photoresists were performed in a stepper system with applied exposure energy of 80, 200 and 300 mJ cm^{-2} respectively. Finally, hard baking was performed at 115 °C for 20 min in an oven. Redeposition rate after etching Au in the ICP system using the standard etch recipe was investigated with these three different photoresists in SEM.

Secondly, the effects of the etch chemistry and the process parameters on the redeposition rate were investigated using the ICP etch system. Standard etch recipe process parameters that were used as the starting point for the optimization of the etch process are listed in table 1.

Table 1. Standard Au etch process parameters.

	Set values
HBr	15 sccm
Ar	5 sccm
Pressure	2 mTorr
RF coil power	800 W
RF platen power	150 W
Temperature	20 °C

Specifically, the effects of the HBr/Ar and Cl_2/Ar gas mixtures with constant gas flow rates were investigated as the etch chemistries. After determining the etch chemistry, the effect of the coil RF and platen RF powers on the redeposition rate were investigated.

For the coil RF power three different set values were applied, 600 W, 800 W and 1000 W by keeping the platen RF power and process time constant, 150 W and 75 s. After determining the optimum coil RF power, three more etch runs were performed to determine the optimum platen RF power by applying three different set values, 50 W, 150 W and 250 W while the coil RF power and the process time were kept constant, 600 W and 75 s. Redeposition rates after each etch process were investigated in SEM.

Redeposition effect on the sidewall of the photoresist for submicron size structures still existed, even after achieving the optimum process parameters. Since using hard mask [5], specifically SiO_2, was not applicable in our process considering the selectivity of the SiO_2 film with the SiN etch stop layer, we have developed a new technique for the prevention of the redeposition of the etched byproducts to the sidewall of the photoresist in which a thin Ti layer is deposited over the patterned photoresist that will act as a hard mask on the sidewall of the photoresist for submicron size structures where the profile angle of the photoresist is almost vertical. A 7 nm thick Ti film was deposited in a sputtering system over the patterned photoresist before the etching process was performed. Schematic drawing of the structure before the dry Au etch process is shown in figure 1.

At the beginning of the etch process, the lateral component of the deposited Ti layer is physically etched away by the incoming ions allowing the etch process of the Au layer. Therefore, the lateral component of the deposited thin Ti film was completely etched away at the beginning of the process and the remaining vertical component of the thin Ti film acting as a hard mask on the sidewall of the small structures was removed by dissolving the photoresist in EKC265 polymer removal after the Au etch process was completed. Then 30 min of O_2 plasma cleaning was also performed to remove the remaining metallic and organic contaminations.

3. Results and discussion

3.1. Effect of the masking material profile angle

The effect of the profile angle of photoresist on the redeposition rate of etched byproducts on the sidewall of the photoresist

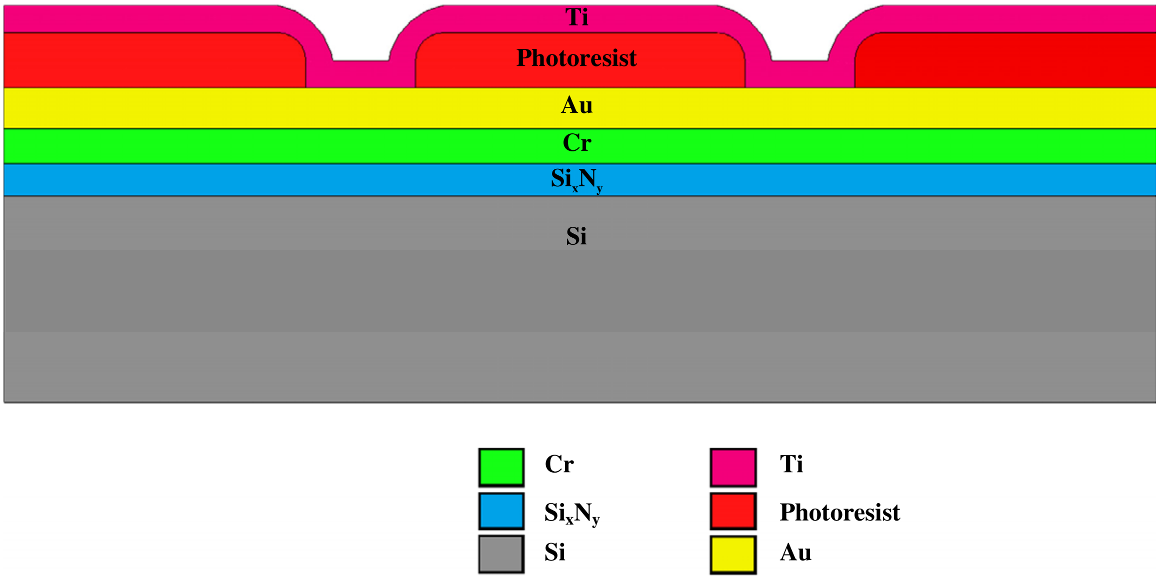

Figure 1. Schematic cross-sectional drawing of the structure before dry Au etch process is performed.

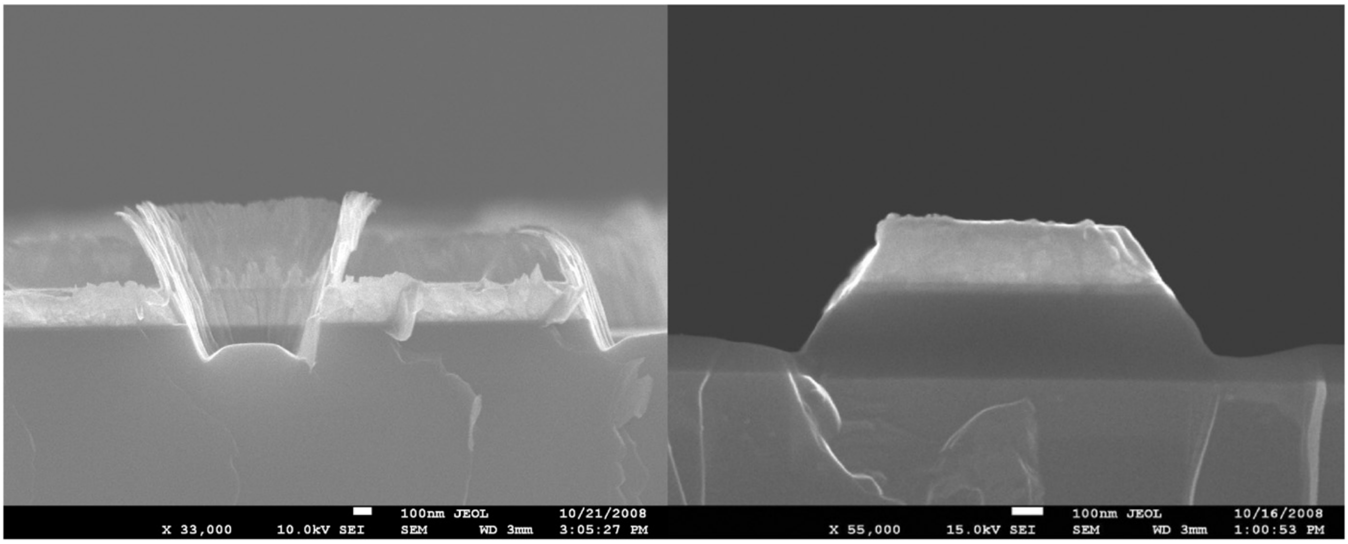

Figure 2. Cross-sectional SEM images of the plasma etched Au thin films using different photoresists. Left: with Ultra-I 123 08, right: with S1805.

has been studied by using three different photoresists, Shipley S1805, S1813 and Ultra-i 123 08.

Figure 2 shows the cross-sectional SEM images of the etched Au thin films using different photoresists. The highest redeposition rate was observed with Ultra-i 123 08-type photoresist in which the profile angle of Au was 70.1°, and the lowest rate was observed with S1805-type photoresist in which the profile angle of Au was 56.6°. Profile angle measurement results for these three photoresists after the hard baking step and the profile angle of the Au layer after etching are given in table 2.

Table 2. Effect of the masking material profile angle.

Photoresist	Sidewall sputtering	Profile angle of photoresists after hard bake	Profile angle of Au after the etch process
Ultra-i 123 08	Yes	78.2°	70.1°
S1813	No	78.4°	60.1°
S1805	No	43.8°	56.6°

3.2. Effect of process parameters

Etch chemistry has been investigated by using HBr/Ar and Cl_2/Ar gas mixtures and setting the process parameters as given in standard Au etch recipe. A decrease in the redeposition rate on the sidewall of the photoresist with the chlorine etch chemistry compared to the hydrogen bromide etch chemistry has been observed. For the rest of the processes Cl_2/Ar etch chemistry has been used.

The effect of coil and platen RF powers has been investigated by applying different RF powers on the

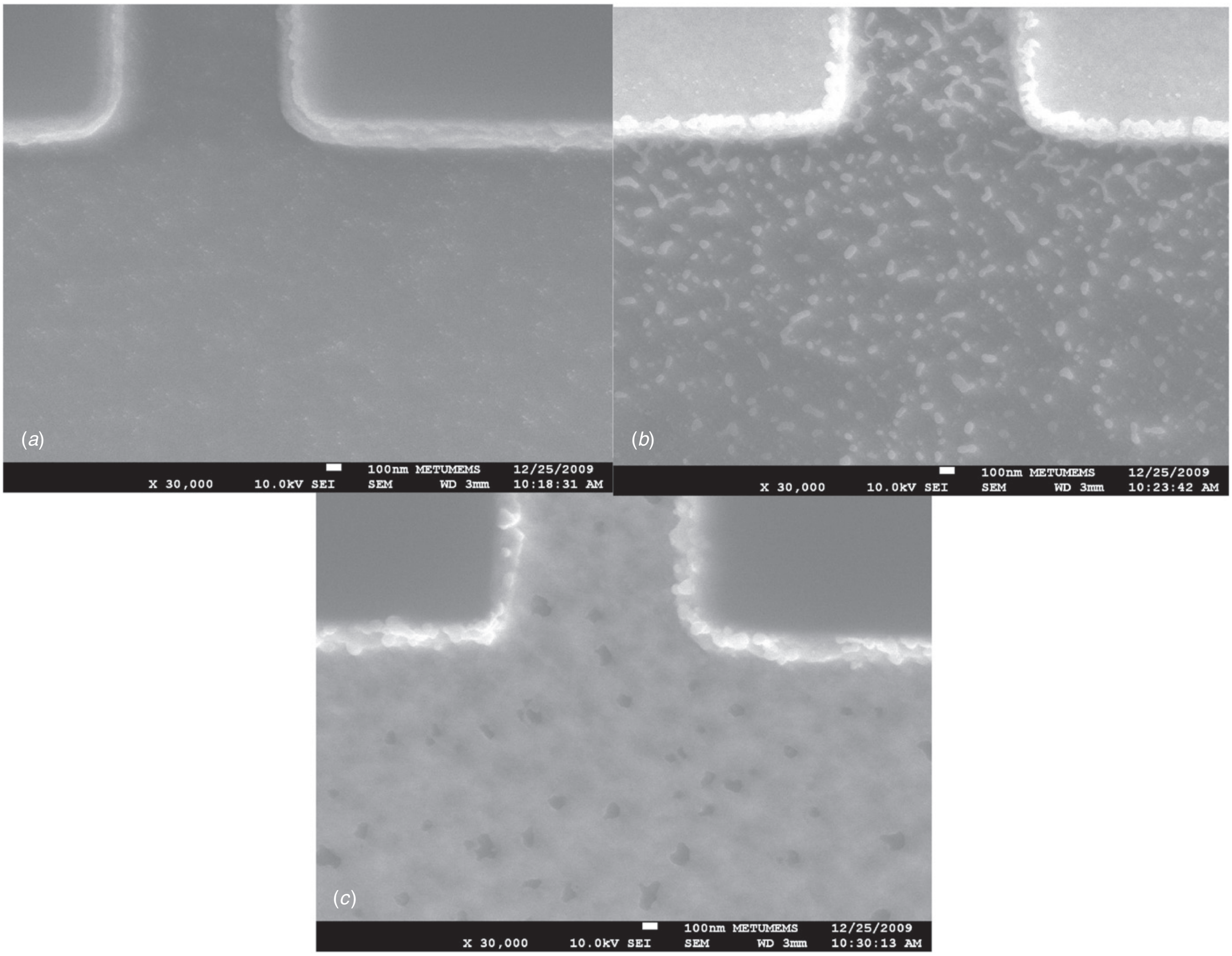

Figure 3. SEM images of the etched Au thin films with different platen RF powers: (*a*) 250 W, (*b*) 150 W, (*c*) 100 W.

redeposition rate of etch Au particles on the sidewall of the photoresist.

First, the effect of the coil RF power was investigated by applying different coil RF powers while keeping the platen RF power and the process time constant. No significant effect on the redeposition rate on the sidewall has been observed with the change in the coil RF power. Only the etch rate and the etch uniformity were affected by changing the coil RF power. Best uniformity results are obtained with 600 W coil RF power.

Second, the effect of the platen RF power was investigated by applying different platen RF powers while keeping the coil RF power and the process time constant. As the platen RF power set value decreases, an increase in the redeposition rate of the etched byproducts on the sidewall of the photoresist and a decrease in the Au etch rate have been observed. On the other hand, the photoresist etch rate also increases with increasing platen power. Optimum results were achieved by setting the platen RF power to 250 W. SEM images of the plasma etched samples are shown in figure 3.

Table 3. Updated Au etch process parameters.

	Set values
Cl_2	15 sccm
Ar	5 sccm
Pressure	2 mTorr
RF coil power	600 W
RF platen power	250 W
Temperature	20 °C

After minimizing the redeposition effect of etched byproducts on the sidewall of the photoresist and improving the etch uniformity, the final dry Au etch recipe has been updated as given in table 3.

3.3. Effect of the deposited thin Ti film

Even after optimizing the lithography step and plasma etch process parameters, there was still redeposition of etched byproducts on the sidewall of the photoresist especially for submicron size structures.

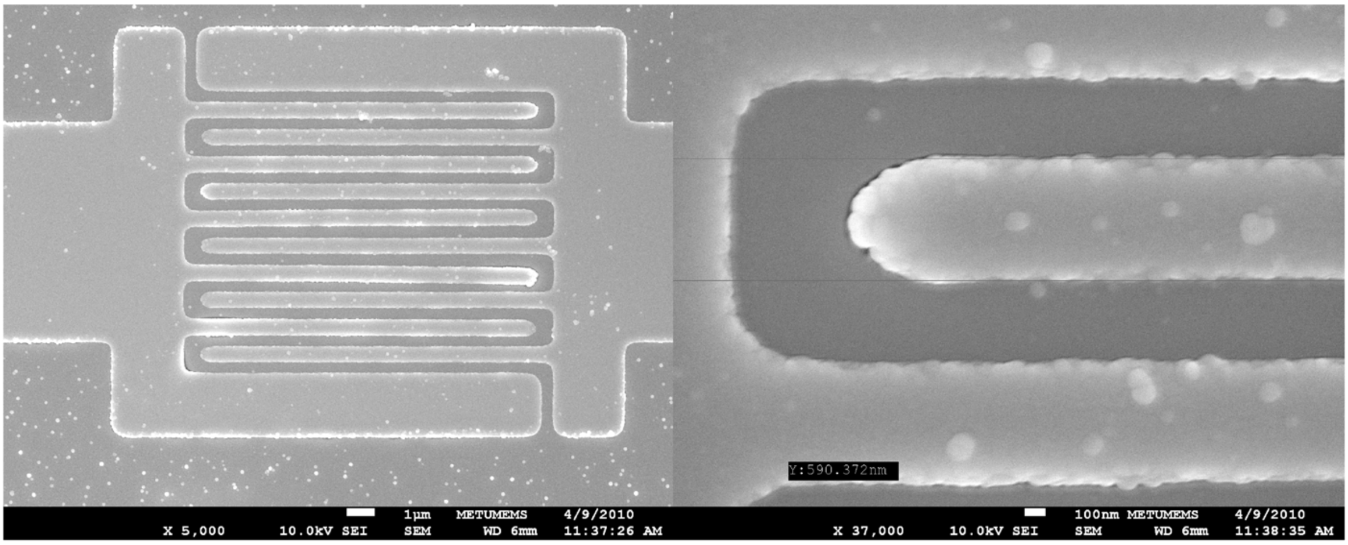

Figure 4. SEM images of Ti deposited structures after the lithography step.

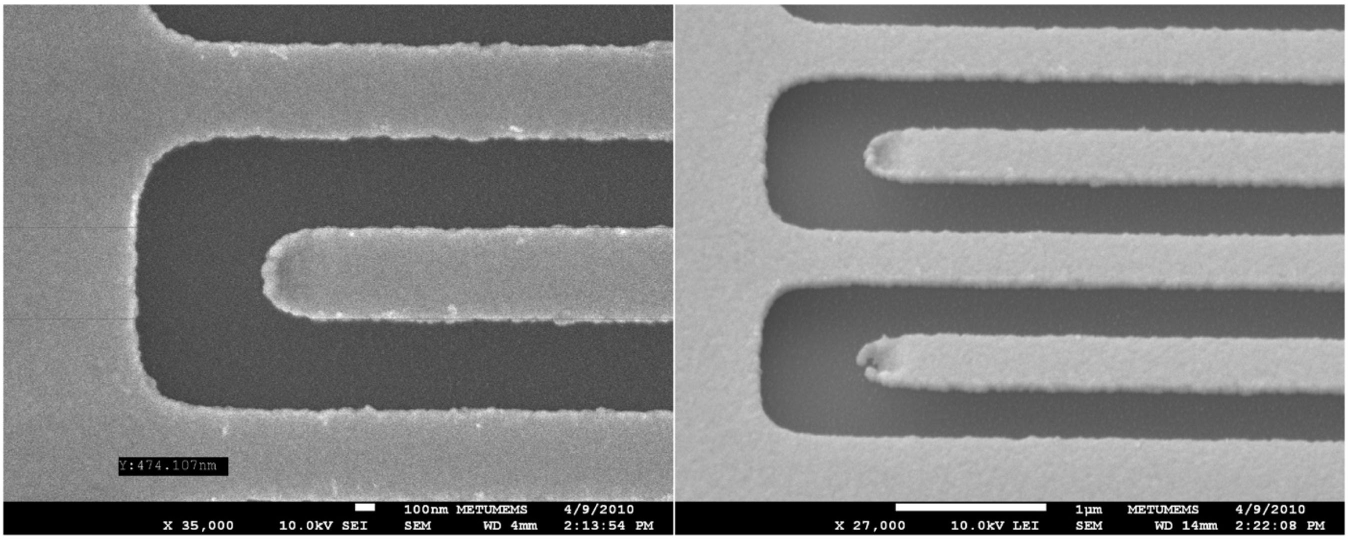

Figure 5. SEM images of plasma etched 0.5 μm wide structures.

In order to prevent this redeposition effect, we have introduced a new technique by depositing a 7 nm thick Ti film over the patterned photoresist that will act as a hard mask to prevent the redeposition of etched byproducts especially for submicron size structures in which the profile angle of the photoresist is almost vertical. For this Au etch run, optimized lithography step and ICP etch process parameters were used. SEM images after depositing a 7 nm Ti layer on the patterned structures are shown in figure 4.

After 75 s of etch process, the photoresist was removed in EKC265 polymer removal and 30 min O_2 plasma run was also performed to clean the remaining organic and metallic contaminations. Figure 5 shows the SEM images of submicron size structures after this cleaning step.

Although Ti is used as an adhesion layer for the deposition of Au, we observed that the formation of veils was eliminated with the deposition of a thin Ti film over the patterned photoresist especially for submicron size structures.

Since the etched byproducts in Cl/Ar chemistry are not pure Au, but instead a mixture of Au and $AuCl_x$ [6, 7, 11], the reaction probability of these byproducts with the Ti compared to photoresist might be low resulting in a decrease in the redeposition rate. SEM images also show a discontinuity and a decrease in the redeposition rate of byproducts to the sidewalls when the proposed technique is used. The SEM images shown in figure 6 were taken before stripping the photoresist.

After optimizing the etch process parameters and lithography step, depositing a thin layer of Ti over the patterned photoresist completely eliminates the veil formation for submicron structures and does not require any postresidue removal processes [8, 11] or using a patterned hard mask [5, 12]. Because we have not observed a sidewall deposition

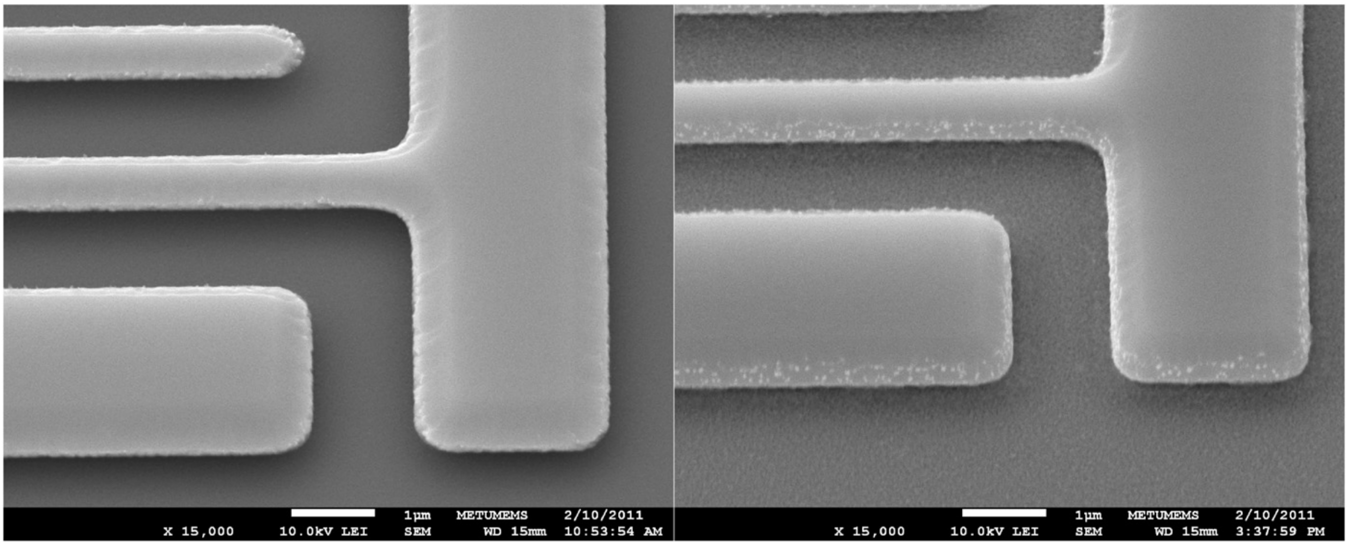

Figure 6. SEM images from two dry Au etch done wafers in which the masking layer is not removed. In the left one the proposed technique was used. The only difference in the right one is that no Ti layer is used over the photoresist in which redeposition of byproducts is observed.

effect on any other materials during dry etch processes, this technique has only been tested on the Au etch process in plasma environments.

4. Conclusion

A new Au etch technique in plasma environments has been introduced to prevent the veil formation after etching Au in a plasma environment using photoresist as an etch mask. The redeposition rate of etched Au particles has also been investigated for two important parameters; the profile angle of masking materials and the ICP process parameters. The redeposition rate is related to the thickness of the photoresist and the profile angle that can be achieved after the hard baking step. ICP etch process parameters have also been investigated in order to reduce the redeposition rate after optimizing the lithography step. Both effects of coil and platen RF powers on the redeposition rate have been investigated. According to results, an update has been made to the etch recipe. Although the improvements made by optimizing the lithography and process parameters were eliminating the redeposition effect for structures with dimensions in the order of micrometer level, the redeposition effect still existed for the structures with submicron dimensions. The reason is that it becomes difficult to give a negative profile angle as the size of the structure becomes smaller. This problem can be eliminated by the technique that has been introduced by depositing a thin Ti layer over the patterned photoresist which will act as a hard mask and prevent the formation of veils after etching Au in plasma environment.

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