LOCAL STRESS FIELD DETERMINATION FOR THIN POLYSILICON FILMS

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ABSTRACT

Local stress field determination by means of free standing structures was investigated. The process for manufacturing these structures was developed and used to study the stress in polysilicon films. For a 1.5um polysilicon film, the stress was determined to be less than 6.77e8Dynes/cm2. For a 0.5um polysilicon films, the stress was found to be 4.09e8Dynes/cm2.

INTRODUCTION

Thin films used in semiconductor technologies include nitride and oxides for passivation, polysilicon and salicides for MOS gates, and aluminum for metal interconnects. The existence of stress in these films may lead to deleterious efeects in device performance. Gate material performance may degrade due to poor adhesion, susceptibility to corrosion, and increased film resistivity. In aluminum lines, stress can lead to void formation and the early ocurrance of the electromigration phenomena. For passivation films, excessive stress can cause films to crack. These problems can lead to unreliable devices and ultimately result in device failure.

The substrate and thin film combination often leads to a state of stress in the film. This total stress is composed of a thermal stress, due to a thermal expansion coefficient mismatch between the two, and an intrinsic stress created by dislocated atoms generating interatomic force fields [1]. The parameter T/Tm (where T is the deposition temperature and Tm the film's melting point) is an important indicator for the determination of the stress in a film. In reaction rate limited CVD films, where the T/Tm exceeds 0.3, thermal stress is the dominant and can be modified by subsequent high temperature thermal treatments in nitrogen or oxygen [2].

A direct result of stress in patterned films, where structures are formed by means of lithographic and etching steps, is a strain field in the structures. Strain is defined as the ratio of length change to the original length.

$$\text{Strain} = dL/L \qquad (1)$$

This length change in the film can result in warpage of the substrate causing concave bending when the length increases

(Tensile stress) or causing convex bending when the length decreases (Compressive stress). The ratio between the stress and the strain is known as the Young's modulus and is characteristic of the material.

Young's Modulus = Stress/Strain (2)

The above relationship of strain field to stress, makes accurate strain measurement a necessity to understand the effects of stress. Work in average strain field determination by means of radius of curvature of warped substrates via optical or mechanical systems has been extensively performed [3]. The major disadvantage of these methods is that they only provide an average strain field for each substrate rather than a local strain field. The advantage of the latter is that it can allow for the mapping of the strain field across the substrate.

By fabricating free standing, doubly clamped beams, an alternative for the accurate determination of local compressive strain fields in thin films has been investigated at University of Wisconsin [4]. Such mechanical structures will buckle due to the strain field in the thin film. Beams of identical cross sections, but changing lengths, were found to be perfectly straight and free of bowing below a critical length. Using the relationship between the beam geometry and the material parameters, Guckel, Randazzo and Burns [4], determined the strain in a buckled beam to be:

E = ((PI**2)(h**2))/(3L**2) (3)

where h is film thickness and L is the beam length.

The free standing beams can be fabricated by using a single masking process where the ends of the beams are supported by pads much larger than the beam. Figure 1 shows such structures.

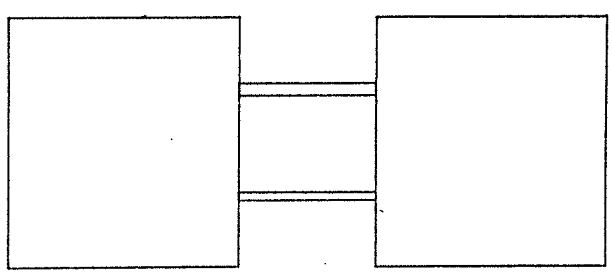

Figure 1: Top View of A Doubly Clamped Beam.

Another compressive stress determination technique is analyzing the edge of a thin film strip that has been undercut. For a compressive film, the edge on view of the film will show a periodic shape [5]. The stress in the film is given by:

S = -E(PI(A)/LAMBDA)**2/(1-v) (4)

where E is Young's Modulus, v is the Poison's Ratio, A is the

periodic film's amplitude and LAMBDA is the wavelength. The periodic shape should be a sinusoidal and a typical edgw view is seen in Figure 2.

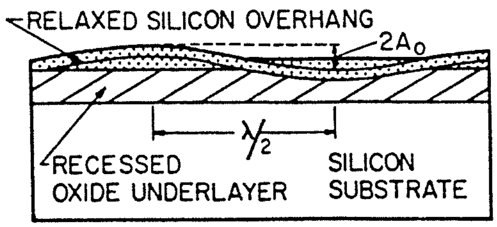

Figure 2: Edge View of Thin Film Overhang.

In this work, stress in polysilicon films was investigated using above two methods. An attempt was made to develop a process for fabrication of the discussed structures. Apart from beams and edges, different sized cantilevers were also designed to see the effect of the residual stress in the polysilicon film.

EXPERIMENT

Integrated Circuit Editor, an inhouse VAX CAD tool, was used to create the mask layout. Doubly supported beams of lengths 25um to 140um were designed. The beam lenghts were incremented by 5um. Two beam widths of 10um and 15um were used. Multiple 400um long edges were also designed. Two sets of cantilevers, singly supported beams, were designed. The lengths were varied from 5um to 100um and widths of 10um and 15um were used. Eight sets of one dimensional springs of different turns were also designed. Figure 3 shows the layout for a single turn 1-dimentional spring. The mask for this layout was fabricated using high resolution emulsion plates.

Ten, 3", <111>, p-type silicon wafers were oxidized in a wet oxygen environment to obtain a 1um thick oxide film to act as a spacer for the polysilicon. Next, a 1.5um thick polysilicon film was deposited on the wafers in a LPCVD reactor using silane at a temperature of 610C.

Using a SF6 and O2 plasma chemistry and a positive resist masking layer, the polysilicon was etched to define the shape of structures. At this point the wafers were ready for the removal of the oxide spacer by means of a highly isotropic and selective etch. Three of the wafers were etched in a Buffered Oxide Etch solution. The BOE allowed for the undercutting of the polysilicon structures without any attack on the polysilicon film. Upon complete undercutting, the structures released. The wafers were water rinsed in a cascade rinser and dried in a convection oven at 85C. Results were evaluatd using interference microscopy and SEM analysis.

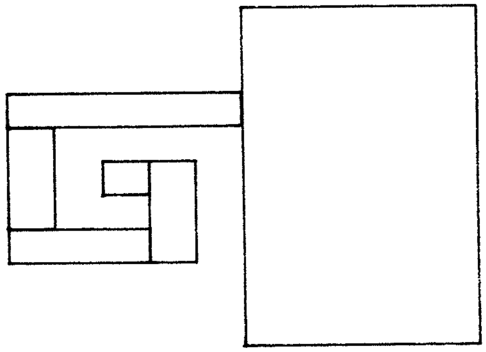

Figure 3: Single Turn Spring.

RESULTS/DISCUSSION

Using interference microscopy, fringe patterns were observed on the structures indicating the buckling of the structures. Further SEM analysis showed that the buckling was in the down direction giving rise to the speculation that the water rinse following the oxide spacer removal, led to a high surface tension formation, thus causing the structures to collapse during the drying cycle. Figure 4 shows a collapsed 110um long beam. At this point it was decided to try different rinse and dry methods following the spacer removal. Two rinse methods were tried on the wafers. One method was a one hour water rinse followed by an isopropyl rinse and the other method was a one hour water rinse followed by a HMDS rinse.

Upon the repeat of the modified experimental procedure, it was observed that most of the 1-dimensional springs and the cantilevers had once again collapsed. However, the doubly supported beam had not collapsed or buckled indicating that there was not enough stress in the longest beam. Using Equation 3, it can be seen that the strain in the longest beam, 140um,was 0.03777%. Using equation 2 and the reported [6] Young's Modulus value of 1.79e12Dynes/cm2 for silicon, the stress for the 140 um beam can be calculated to be 6.77e8Dynes/cm2. Since buckling was not observed in the beam, it can be concluded that the stress in the film was less than 6.77e8Dynes/cm2. The experiment was repeated with a 0.5um polysilicon film. This time buckling was observed in some of the beams as shown in Figure 5.

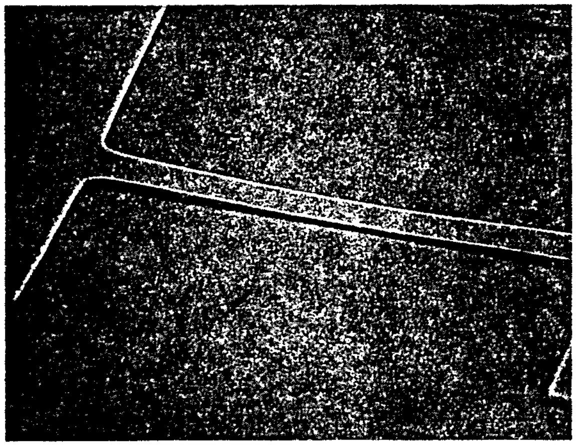

Figure 4: 110umx15um Collapsed Beam.

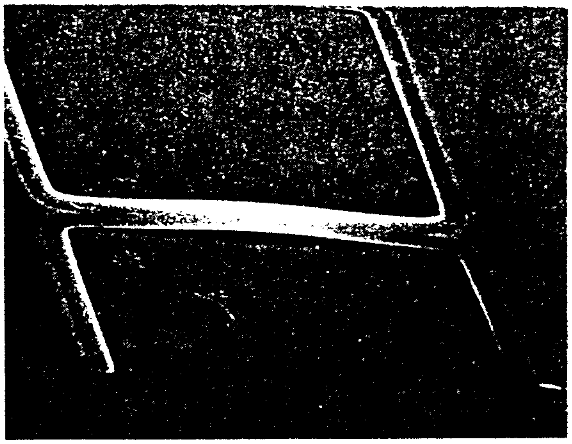

Figure 5: 140um Buckled Beam.

The smallest beam that had buckled was 60um representing a stress of 4.09e8Dynes/cm2. While these two values indicate a very low stress field in the polysilicon film, it should be noted that values are relative to each other and the calculated stress depends of the Young's Modulus value used. For value used in this experiment,it is not known wether the value is for sigle crystalline silicon, amorphous silicon, or polysilicon. It should also be noted that there were some double supported beams that had still collapsed. Since the other structures had also collapsed due to the surface tension problem, their analysis was not performed. The edge of the undercut polysilicon films was looked by SEM but the limitaıon on the equipment did not allow for a high resolution image of the edges and thus an analysis as not performed.

CONCLUSION

Local stress field determination with an application to polysilicon was investigated. Free standing polysilicon structures were fabricated using a single masking process. Surface tension build up following a required water rinse step led to the collapse of the structures. This problem was reduced by rinsing the wafers in alcohol or HMDS following the water rinse. The only structures that did not collapse were the doubly supported beams. It was found that for a 0.5um polysilicon film, the stress was 4.09e8Dynes/cm2. For a 1.5um film the stress was found to be less than 6.77e8Dynes/cm2. It was determined that these two values are relative to each other and an accurate stress value requires a very precise measurement of the Young's Modulus of Elasticity for polysilicon.

ACKNOWLEDGMENTS

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