Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo, 1987, pp. 435-438

S-II-9

Low Resistive, High Aspect Ratio Via-Hole Filling System Completely Planarized by Selective W Deposition and Subsequent Etch-Back

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A high aspect ratio via-hole filling system for multilevel interconnection has been developed using a selective tungsten deposition and subsequent etch-back method. In the etch-back process, non-selective etchings between W, WSix, MoSix and organic material were performed. With this newly developed system the surface was perfectly planarized and the structure exhibited thermal stability even after annealing at 900°C.

INTRODUCTION

Vertically stacked devices, such as three dimensional(3-D) LSIs,[1)2)] are attractive for higher density LSIs and artificial intelligence devices. Multilevel interconnection[3-5)] is the most important technique in these stacked devices. In particular, a high aspect ratio via-hole filling technique[6)] which maintains low resistivity and thermal stability even after high temperature processing is a key technology. Metallization of a high aspect ratio via-hole is difficult because conventional CVD or sputter films give poor step coverage. Selective tungsten deposition is the most effective technology for sub-micron via-hole filling. High rate deposition is necessary for deep via-hole filling while maintaining selectivity and suppressing lateral encroachment. However, in a high rate deposition, surface steps caused by grains of tungsten grow about half micron on the surface, and these steps cause an obstruction to fine pattern formation and a deterioration of device reliability.

In this paper, a newly developed via-hole filling system which can be applied to the complete and simultaneous planarization of various depth via-holes is described. The electric characteristics and thermal stability of this structure are then described.

PROCESS DESCRIPTION

The via-hole filling process is shown in Fig. 1. A first level metallization consists of a refractory metal silicide and surface steps are planarized by an etch-back of an interlevel insulation layer. Next, selective tungsten is deposited after via-hole definition. Subsequently, the etch-back of refractory metals or their silicides with an organic material (polyimide) is performed after coating. In the case of an over-filling process, tungsten and polyimide are etched at the same rate. In the case of a half-filling process, MoSix(WSix) and polyimide are etched in the same way. Finally, MoSix is deposited by sputtering on the planarized surface as a second level metallization.

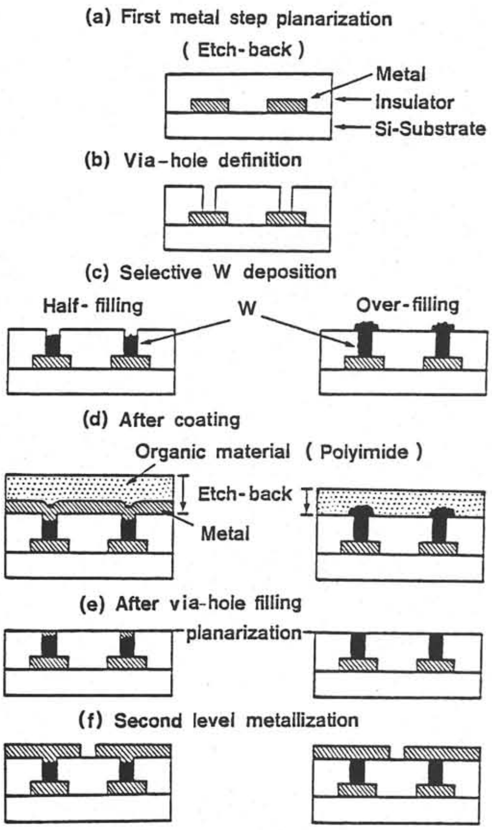


Fig. 1 Process sequence of the via-hole filling by etch-back of either refractory metals or their silicides

In a real device structure, via-hole filling with different depths is required. In this case, these via-holes can be filled simultaneously using two non-selective etchings for over- and half- fillings. In this study, selective tungsten deposition was performed in a cold wall type reactor using WF_6 and H_2 at 450°C. The etch-back was performed using a cassette to cassette RIE single wafer system.

RESULTS AND DISCUSSION

1) Non-selective etching

The conditions for non-selective etching in the etch-back process were obtained with a mixed gas of CF_4 and O_2 for polyimide/MoSix, polyimide/WSix and polyimide/W systems, respectively. The variation in etch rates of MoSix, WSix, W, polyimide and SiO_2 as a function of the gas pressure is shown in Fig. 2. These non-selective etching conditions can be obtained in other gas systems. The etch-back process has problems peculiar to the process itself, for example, the uniformity of the etch-rate and how to determine the end of etching, because they all influence the accuracy of the planarization. The uniformities under conditions of non-selective etching obtained here were below 3% within a wafer. The end point of this process could be detected by monitoring the F emission intensity of the reaction species.

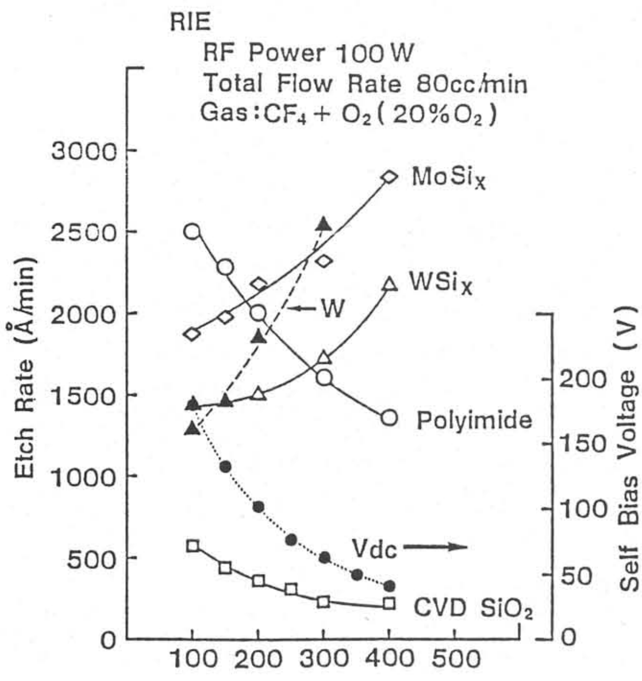


Fig. 2 Etching rates of various material

2) Via-hole filling

Fig. 3 shows the oblique-directional view of the via-holes after selective tungsten deposition. The selectivity was perfectly maintained and lateral encroachments were less than 0.1μm after 1.6μm deep filling, but the surface of the tungsten was irregular.

Fig.4 shows the cross-sectional views of a via-hole obtained by the over-filling process. The via-hole depth and width were

1.6µm and 0.8µm, respectively. The aspect ratio of the via-hole was about 2. Tungsten overgrew itself to about 0.8µm in height after deposition, but this surface step was reduced to 0.1µm by the etch-back of tungsten with polyimide. Using the half-filling process, the 1.6µm via-hole step was reduced to 0.1µm in the same way , and no void was observed in the hole, but the surface was not smooth. This surface chap was attributed to the morphology of grains in the underlying tungsten film. Under this etching condition, the reaction is chemical. The etch rate in chemical reactions varies among grains because of the differences in the film quality. The problem of the surface chap can be solved by improving the etching conditions.

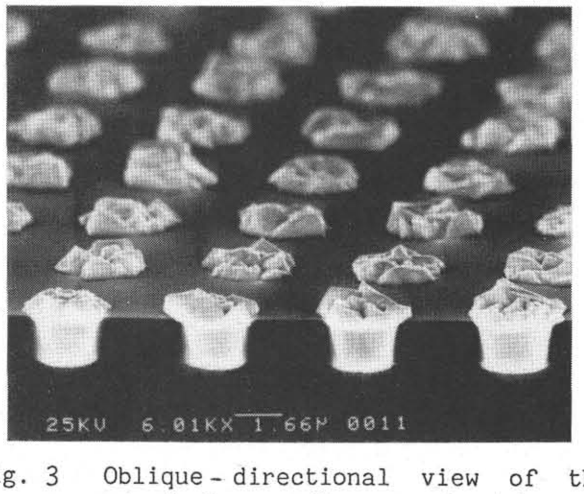
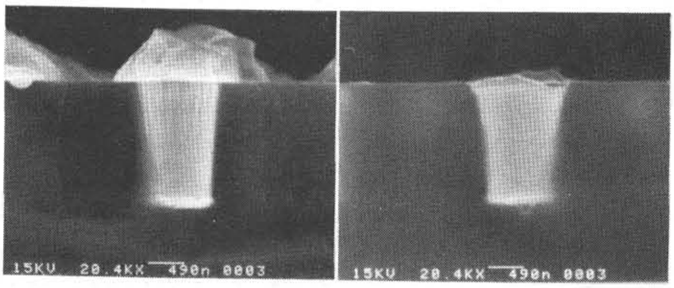


Fig. 3 Oblique-directional view of the via-holes after selective W deposition



(a) After W deposition (b) After etch-back

Fig. 4 Cross-sectional views of the via-hole obtained by the over-filling process

In real device structures, via-hole filling of different depths is required. Furthermore, the deposition rates of selective tungsten differ with the underlying layers, for example, the deposition rate on a metal silicide is much higher than that on Si substrate. Thus, the etch-back process is more important in obtaining a planarized surface. Various depths of via-holes can be filled simultaneously by using the over-filling process together with the half-filling process.

3) Via-hole resistivity

The specific via-hole resistivities after 900°C annealing as a function of the via-hole size are shown in Fig. 5.

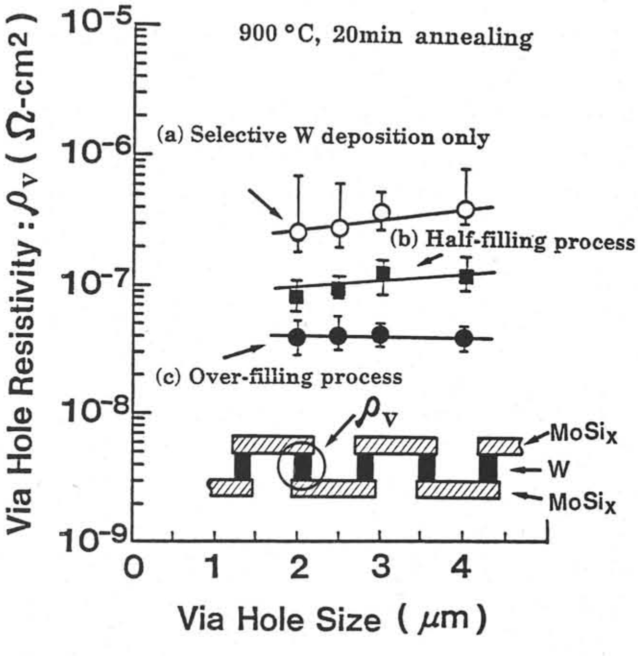


Fig.5 Comparison of via-hole resistivities;
(a) Via formed by only tungsten deposition,
(b) Via formed by half-filling process,
(C) Via formed by over-filling process

The resistivity of the reference sample obtained by only selective tungsten deposition was $4 \times 10^{-7} \Omega \cdot cm^2$. The resistivities of the samples obtained by the over-filling process and the half-filling process were $4 \times 10^{-8} \Omega \cdot cm^2$ and $8 \times 10^{-8} \Omega \cdot cm^2$, respectively. The variations in resistivities were considerably smaller than that of only selective tungsten deposition system. The electrical characteristics are improved by the smoothing of the irregular tungsten surface. It seems that these reasons are attributed to the deterioration of the step coverage and micro-cracks in the upper layer of MoSix, and these problems can be solved by introducing the etch-back method.

4) Thermal stability

For determination of metal silicide composition as the first and second level interconnections, good thermal stability of the metal silicide/W/metal silicide structure is necessary in order to endure the subsequent high temperature processes. Fig. 6 shows the X-ray diffraction patterns of the W/MoSix structure after annealing at 900°C. In the W/$MoSi_{2.4}$ structure, tungsten reacted with Si in MoSix after annealing. However, in the W/$MoSi_{2.0}$ structure, tungsten did not react with Si in MoSix even after annealing at 900°C. This means that the tungsten reacted only with superfluous Si in the MoSix.

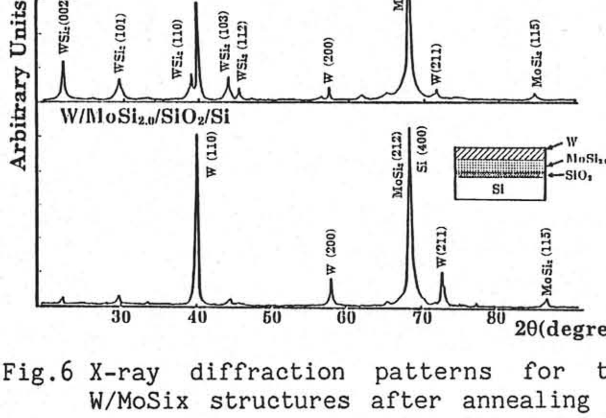


Fig.6 X-ray diffraction patterns for the W/MoSix structures after annealing at 900°C

SUMMARY

A new, high aspect ratio via-hole filling technique using selective tungsten deposition and subsequent etch-back of refractory metals or their silicides has been developed. With this newly developed via-hole filling system, low and uniform resistivity of the via-hole with complete planarization and thermal stability has been realized. This technology is useful for 3-D LSIs and the higher density LSIs expected in the future.

ACKNOWLEDGEMENT

The authors wish to thank Dr.S.Kataoka for his continuous encouragement.

This work was performed under the management of the R&D Association for Future Electron Devices, as a part of the R&D Project of Basic Technology for Future Industries, sponsored by Agency of Industrial Science and Technology, MITI.

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