Extended Abstracts of the 17th Conference on Solid State Devices and Materials, Tokyo, 1985, pp. 329-332

New Planarization Technology Using Bias-ECR Plasma Deposition

KATSUYUKI MACHIDA and HIDEO OIKAWA

NTT Atsugi Electrical Communication Laboratories,
3-1 Morinosato Wakamiya, Atsugi-Shi, Kanagawa, 243-01 Japan

A new technology to planarize submicron interconnections with high aspect ratio(height/space of interconnection) has been developed by applying rf bias to the substrate of ECR (Electron Cyclotron Resonance) plasma deposition system. Features of Bias-ECR plasma deposition are as follows;(i) it can planarize the concave region of submicron interconnections since deposition particles of ECR plasma have the vertical directionality, (ii) the planarization condition is more controllable since both deposition and etching rates are controlled by gas flow rates besides rf and microwave powers and (iii) the planarization time is shortened by applying rf bias from the first stage of process because of the sputter etching of O_2 ions without Ar. Using the Bias-ECR plasma deposition technology, the surface of 0.5um L&S Al interconnections with 0.5um thickness can be perfectly planarized.

I. Introduction

The planarization technology for the multi-level interconnection of VLSI has become more important with higher density integration. For submicron interconnections, the aspect ratio (height/space of interconnection) becomes near to or higher than 1.0 since the thickness of interconnection metal can not be decreased in proportion to pattern size reduction.

Recently, bias-sputtering deposition[1] has attracted special interest as the planarization technology. However, for conventional sputtering deposition, deposition particles have mainly the oblique incident angle to the substrate so that the intermediate insulator film can not be deposited in the concave region between interconnections as the aspect ratio becomes near to or higher than 1.0. Thus, it will become difficult to obtain the planar structure of submicron interconnections by bias-sputtering deposition.

A new technology applying rf bias to the substrate of the ECR (Electron Cyclotron Resonance) plasma deposition system[2] to planarize submicron interconnections with high aspect ratio is proposed. (Hereafter it is called Bias-ECR plasma deposition.) The ECR plasma deposition is suitable for submicron multi-level interconnections with the high aspect ratio since plasma particles have the vertical incident angle to the substrate.

In this paper, the Bias-ECR plasma deposition system is described first. Next, the principle of planarization and the characteristics of the Bias-ECR plasma deposition are discussed. Finally, application of this planarization technology to the 0.5um L&S Al interconnections is presented.

II. Bias-ECR Plasma Deposition System

The diagram of the Bias-ECR plasma deposition system is shown in Fig.1. In the ECR plasma deposition method, the insulator film can be deposited at a low range of temperature (50 to 150 °C) in relatively low gas pressure (10^{-5} to 10^{-3} Torr). For the ECR condition, the microwave frequency is 2.45GHz and the magnetic flux density is 875Gauss. By applying rf bias to the substrate of the ECR plasma deposition system, the sputter etching at the surface of the specimen can be occurred by the bias voltage and the ions. Frequency of rf generator is 13.56MHz. The substrate is water-cooled.

By introducing O_2, N_2 and Ar gas from gas tube(1) into the plasma chamber and SiH_4 from

from gas tube(2) into the specimen chamber, the insulator film is deposited by the ECR plasma deposition method or is etched by rf bias.

III. Principle of planarization

(A) Conditions needed for planarization

The principle of the planarization of interconnections using the sputter etching is discussed from the viewpoint of the deposition method. As shown in Fig.2, the surface of interconnections is classified into two regions; one is the convex region with the wide space between interconnections, the other is the concave region with the high aspect ratio above 1.0. Here, D_f, D_s and D_b are defined as deposition rates of the convex, side and concave surfaces, respectively. E_f, E_s and E_b are also as etching rates of the convex, side and concave surface, respectively. As the condition for planarization using the sputter etching, the relations of $D_s<E_s$ and $D_f \geq E_f$ in addition to $E_s>E_f$ have been emphasized. (Here, it should be noted that the condition of $D_s>E_s$ is maintained in the initial stage of planarization so that the edge and surface of the metal is not etched.) However, this condition is sufficient only for a convex region but not for a concave region. If the deposition rate at flat surface D_f is larger than that at the bottom surface of concave region D_b, the planarization can not be obtained. D_b is strongly dependent upon the incident angle of deposition particles. As for the direction of deposition particles , there are two types of deposition method. One has an oblique incident angle and $D_f>D_b$, the other has a vertical incident angle and $D_f=D_b$. For the deposition method of $D_f>D_b$, the concave region width becomes larger with sputtering time because of $E_s>D_s$. On the other hand, for the deposition method of $D_f=D_b$, the concave region can be planarized.

Therefore, the condition $D_f=D_b$ is needed in order to planarize the concave region in submicron interconnections. In the next section, from the viewpoints of aspect ratio and filling ratio in the concave region, the relationship between D_f and D_b is investigated with the conventional sputtering deposition and the ECR plasma deposition.

(B) Aspect ratio dependence of filling ratio

The relationships between aspect ratio(H/S) and filling ratio(b/a) are shown in Fig.3 for both the ECR plasma deposition and the conventional sputtering deposition without rf bias. For the ECR plasma deposition, the filling ratio(b/a) becomes larger than 0.9 for the aspect ratio(H/S) of 1.0 and, furthermore, 0.8 even for the aspect ratio of 2.0. On the other hand, for conventional sputtering deposition, the filling ratio is small, 0.6 for the aspect ratio of 1.0.

As the result, ECR plasma deposition with high directionality can planarize submicron interconnections with high aspect ratio. Therefore, ECR plasma deposition is superior to conventional sputtering deposition for the submicron interconnection.

IV. Characteristics of Bias-ECR Plasma Deposition

The characteristics of SiO_2 deposition by the Bias-ECR plasma deposition method is investigated. The relationships between the SiO_2 deposition rate and rf power for constant microwave power(200w) and gas flow rates($SiH_4$20sccm,$O_2$20sccm,Ar30sccm) are shown in Fig.4. From the figure it is found that (i) the deposition rate of SiO_2 decreases with the increase in rf power and (ii) SiO_2 is etched by O_2 ions or Ar ions due to a bias voltage. It is remarkable that SiO_2 is etched only by the O_2 ions without Ar. Moreover, Bias-ECR plasma deposition can perform planarization of the surface on Al interconnections with rf bias because the sputter etching of O_2 ions at the surface and edge of Al interconnections is very much smaller than that by Ar ions. On the other hand, for conventional bias-sputtering deposition, the surface and edge of Al interconnections are etched by Ar ions. Thus, for Bias-ECR plasma deposition, the planarization time is shortened by applying rf bias to the substrate from the initial stage because Al is not etched by O_2 ions without Ar.

The relationships between the SiO_2 deposition rate and SiH_4,O_2 gas flow rates for rf bias with Ar gas as a parameter are shown in Fig.5. Here, the microwave power is constant(200w). The deposition rate of SiO_2 increases with the increase in the gas flow rate of SiH_4 and O_2. Besides, the deposition rate of SiO_2 decreases due to the sputter etching of rf bias. Thus, for Bias-ECR plasma deposition, the degree of deposition and etching rates can be easily controlled by the gas flow rates without changing rf and microwave powers. However, for conventional bias-sputtering deposition method, the degree of deposition and etching rates can be controlled only by bias voltage. Therefore, Bias-ECR plasma deposition is the technology by which it is easy to control the condition of planarization.

V. Application to surface planarization

This technology was applied to submicron Al interconnections. Al interconnections were fabricated by electron beam lithography and reactive ion etching. An SEM micrograph of submicron Al interconnections using this planarization technology is shown in Fig.6. Al interconnections are 0.5um L&S with 0.5um thickness. The planarization process consists of the following two stages; (i) SiO_2 is deposited by Bias-ECR plasma deposition without Ar gas to the thickness of the Al interconnections, and (ii) SiO_2 is deposited, adding Ar, in which an etching rate larger than that of the first stage is selected. As shown in Fig.6, the surface of 0.5um L&S Al interconnections can be perfectly planarized.

VI. Conclusion

The Bias-ECR plasma deposition planarization technology newly developed is suitable for submicron interconnections with high aspect ratio. The reason is due to the fact that the concave region of submicron interconnections can be planarized since ECR plasma deposition has the high vertical directionality. The other advantages are as follows;(i) the planarization time is shortened by applying rf bias to the substrate in the gaseous environment with SiH_4,O_2 from the initial stage since the surface and edge of Al interconnections are scarcely etched by O_2 ions and (ii) the degree of the deposition and etching rates can be largely changed by gas flow rates besides rf power.

Acknowledgments

The authors would like to thank Drs. Mamoru Kondo, Eisuke Arai, Susumu Muramoto and Seitaro Matsuo for their advice and encouragement. They are also grateful to the staff personnel in the Patterning Technology Section of the Atsugi Electrical Communication Laboratories for sample preparations.

References

(1)C.Y.Ting,etal,J.Vac.Sci.Technol.,15(3),May/June 1978, pp1105-1112.

(2)S. Matsuo and M. Kiuchi, Jpn. J. Appl. Phys. Lett., 22 (1983) L210.

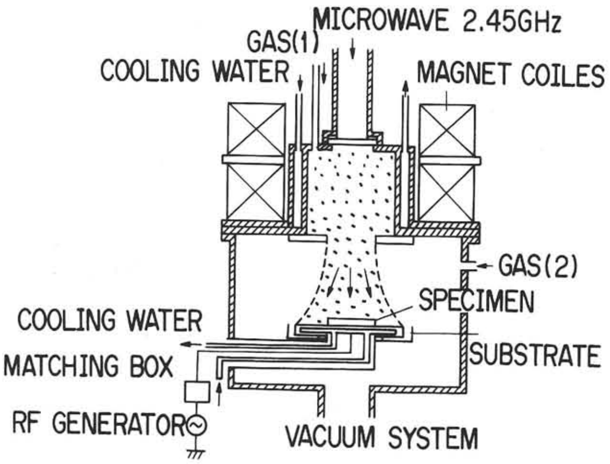

Fig.1 Diagram of Bias-ECR plasma deposition system.

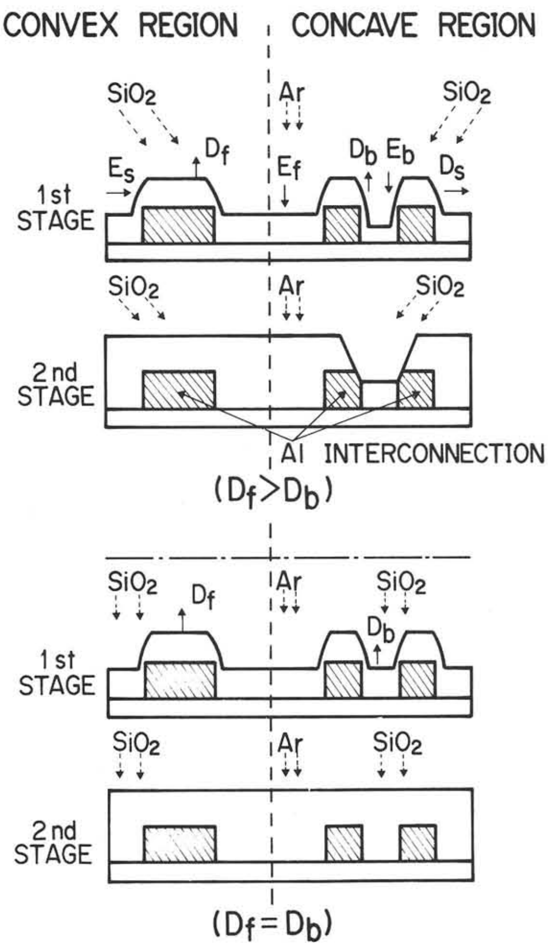

Fig.2 Principle of planarization.

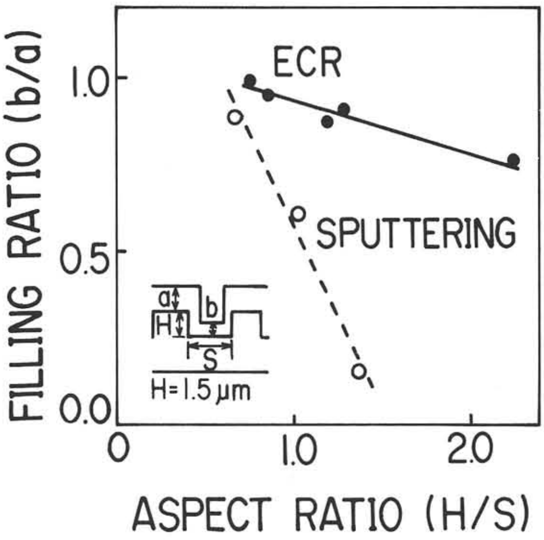

Fig.3 Aspect ratio dependence of filling ratio.

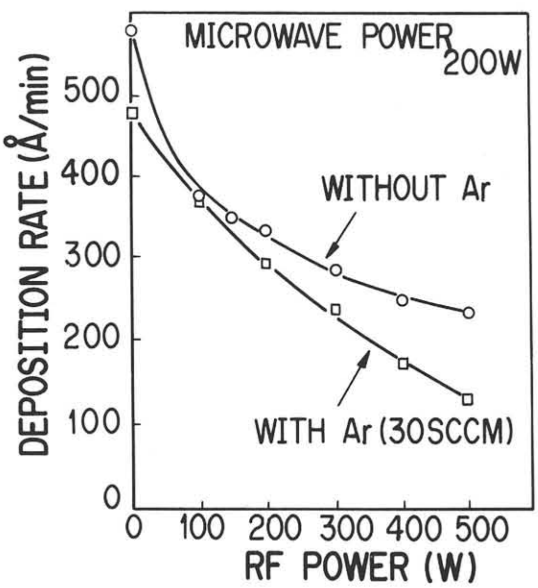

Fig.4 Rf power dependence of deposition rate. SiH_4, O_2 flow rates are 20(sccm), respectively.

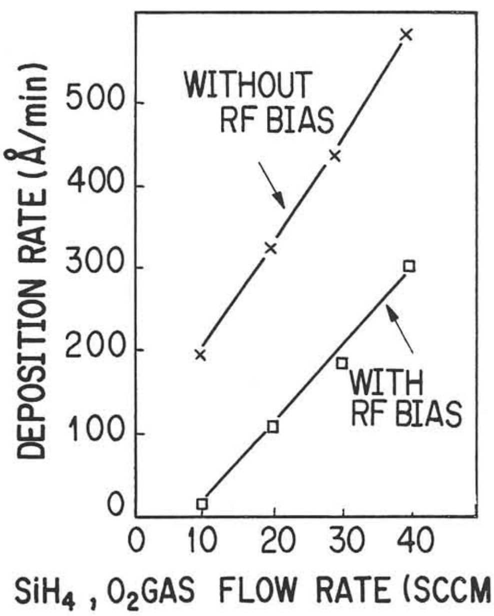

Fig.5 Gas flow rates dependence of deposition rate. The flow rate of SiH_4 is equal to that of O_2. Rf and microwave powers are 200(w), respectively. Ar(30sccm) is introduced into the chamber only with rf bias.

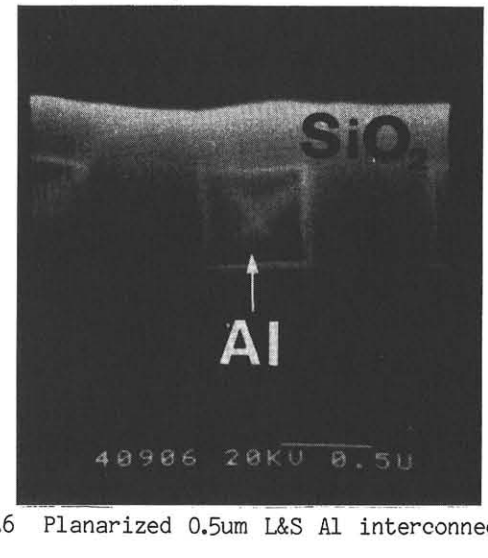

Fig.6 Planarized 0.5um L&S Al interconnections.