Influence of an Insulating Film on Plasma Silicon Dioxide Deposition Rates

Radko Osredkar[1]

International Microelectronic Products, San Jose, California 95134

ABSTRACT

The dependence of plasma silicon dioxide deposition rates on the thickness of underlying electrically insulating thermal oxide grown on sample wafers prior to plasma deposition has been studied. Insulating films can reduce the deposition rates by approximately 25% if both wafers facing each other in the susceptor assembly are insulated from it, and by approximately 15% if only one is insulated. A semiquantitative description of the effect is given, based on variations of RF plasma excitation power due to insulating target wafers from the susceptor.

Working with certain types of plasma deposition equipment, it seems to be a common experience that the generally good wafer to wafer uniformities of deposited films of plasma silicon dioxide on device wafers often cannot be reproduced in depositions with mixed loads of device and test wafers. Films on device wafers would consistently be deposited at a different rate than on test wafers, and sometimes even test wafers between themselves would demonstrate widely differing deposition rates. This anomalous behavior of deposition rates often cannot be attributed to any of the usual causes of nonuniform deposition, such as changed flows of reactant gases, arcing, excessive deposits on the susceptor, etc.; but more exotic causes must be contrived.

In this paper, we demonstrate that under certain controlled conditions, the anomalous behavior of deposition rate of plasma silicon dioxide can be attributed to poor electrical contact between wafers and susceptor, caused by a thin layer of silicon dioxide on the back sides of wafers, deposited or grown prior to plasma deposition. A semiquantitative analysis of the effect is also presented.

Experimental

The plasma deposition reactor used in this work is a commercial vertical parallel plate PWS 450 Coyote system. Details of the layout, construction, and operation of this system, as well as of a conceptually similar one, are well documented (1, 2).

Briefly, the PWS 450 Coyote comprises a parallel vertical plate graphite susceptor assembly inserted into a LPCVD-type 8 in. quartz tube in a resistance heated furnace. The 11 plates of the susceptor assembly carry tapered attachment buttons that hold wafers in an upright position during the deposition cycle, with the backs of the wafers in electrical contact with the graphite plates. The power outputs of a RF power supply are alternately connected to every other plate of the assembly. The RF plasma discharge is maintained between the plates of the susceptor assembly, with pairs of facing wafers being in effect the electrodes between which the discharge takes place. There is space for 70 wafer pairs in a susceptor assembly. Throughout the tests of this study, 9 wafer pairs, *i.e.*, 18 wafers, located at fixed positions on the susceptor assembly during depositions were used for measurements, with all other locations being occupied by dummy wafers.

The RF power supply is operated in a pulsed mode, the average power of plasma excitation during a silicon dioxide deposition being 90W, and output impedance of the power supply matched to the impedance of the susceptor assembly at 100Ω for 125 kHz operation. The RF is continuously variable from 25 to 125 kHz.

Deposition uniformity is achieved with relatively large flows of reactant gases, 0.2 liter/min of silane SiH_4, 2.8 liter/min of nitric oxide NO, and 0.5 liter/min of argon as carrier gas. Pressure in the reactor chamber is held constant at 1.4 torr during deposition, and temperature is 380°C. At these conditions, the deposition rate of plasma silicon dioxide is approximately 400 Å/min and deposition uniformity is generally within ±5% over the entire susceptor assembly.

The thicknesses of deposited films were measured optically with a Nanometrics Nanospec AFT and a Gaertner G 117 ellipsometer, which was also used to measure the refractive indexes of the films.

Results and Discussion

Results of identical depositions of plasma silicon dioxide on different wafers with dissimilar histories before the deposition are presented in Fig. 1. Each point on the diagram represents average thickness and average refractive index of films deposited on several wafers (usually 6-10) that were in as nearly as possible identical condition before the deposition. It is obvious that large differences in thickness and refractive index of deposited films exist between device wafers that have back sides etched to bare silicon (T = 10,800Å, n = 1.40) at one extreme, and wafers with 300A of thermal silicon dioxide grown on both sides of wafers prior to plasma deposition (T = 7700Å, n = 1.465) at the other. Contrary to what one might expect, fresh wafers, as delivered from the vendor, had deposited plasma silicon dioxide films more closely resembling those of wafers that had been previously oxidized than device wafers, with clean back sides. Without attempting to define in detail the target wafer condition prior to deposition, which is difficult to do in a useful manner but can hopefully be achieved reproducibly by preparing the wafers with set routines, and correlating them with properties of deposited film, we note that film refractive index and its thickness are related, so that as T increases, n decreases linearly. The empirical relation between them is

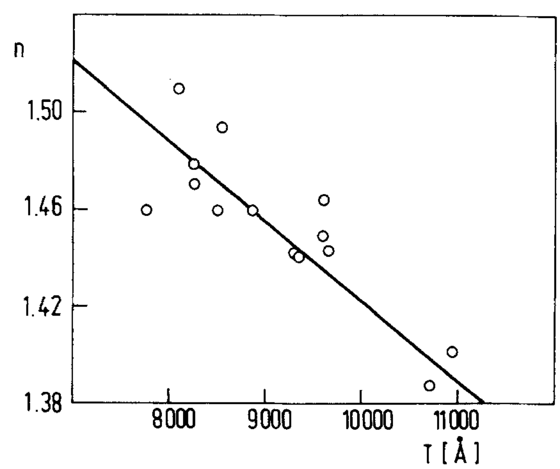

Fig. 1. Refractive index n vs. film thickness of plasma silicon dioxide films deposited during identical deposition cycles. Deposition time t = 23 min, ν = 125 kHz.

[1]Present address: E. Kardelj University, Faculty of Electrical Engineering, Microelectronics Laboratory, Trzaska 25, 61000 Ljubljana, Yugoslavia.

$$n = 1.75 - 3.29 \times 10 \exp(-5) \times T \quad [1]$$

where T is in angstroms (Å), for deposition conditions described in previous section.

It is known and well documented that the refractive index of plasma-deposited silicon dioxide films linearly decreases as the RF power with which the plasma is excited increases (3), or is inversely proportional to the RF power (4). This dependence is similar to the one observed in plasma-deposited silicon nitride films (5), and may well be a general feature of all plasma-deposited films where the deposition is limited by the generation rate of reactive species in the discharge. Further, in a generation-limited deposition situation, the deposition rate and the RF excitation power are linearly proportional to a high degree as illustrated, *e.g.*, by the work of Ellenberger (6). Therefore, the dependence of the refractive index on deposition rate is the same as its dependence on RF plasma excitation power to a multiplicative constant, if all other parameters of deposition are held constant.

According to the above, Fig. 1 can be viewed as representing the dependence of the refractive index of deposited films on the local plasma excitation RF power. Since the RF power delivered to the susceptor assembly from the power supply is constant, and the whole susceptor assembly is conductive (its surface is, therefore, equipotential), the differences in excitation power between certain wafer pairs are a consequence of different resistance of the electrical contact of these wafers to the susceptor.

In order to investigate further the effects of electrical contact between wafers and susceptor on deposition rate, samples of wafers with different thicknesses of thermal oxide grown prior to plasma deposition were used as deposition targets. Results are presented in Fig. 2. It is evident that the deposition rate of plasma oxide on a wafer is reduced as soon as there is an insulating film on the back side of the wafer. This reduction does not depend, within experimental error, on the thickness of this film, but it does depend on the condition of the facing wafer. If both facing wafers are electrically insulated from the susceptor, full reduction of the deposition rate can be observed. If only one of them is insulated and is facing a clean wafer, the reduction on both wafers is approximately half as much. It seems that in case of very thin insulating films (approximately 100Å), their integrity can be destroyed during loading of wafers into the susceptor, and electrical contact between wafer and susceptor can be established, thus causing the scatter of the data for the 100Å and thinner films. However, attempts to measure this directly were unsuccessful. In these cases, the deposition rate increases from the value of insulated pairs to the intermediate one, or to the value of uninsulated pairs if films on both wafers are damaged.

A relatively simple and semiquantitative analysis of the situation presented above is possible. The impedance of the loaded susceptor assembly during plasma silicon dioxide deposition at 125 kHz is resistive (7) and is 100Ω, *i.e.*, approximately 8000Ω per wafer pair, allowing for plasma generation in volume between susceptor plates not covered by wafers. By far the largest contribution to the total impedance of a wafer pair during a deposition is the impedance of the plasma itself. If two facing wafers are electrically insulated by a film from the susceptor, they are coupled to it via the plasma discharge between their back sides and the susceptor surface. The impedance of this coupling is added to the impedance of plasma generated between these two wafers. The voltage at the susceptor does not change appreciably because of this extremely small change of total susceptor impedance, but RF power of plasma excitation between the two wafers under consideration is reduced by a factor of

$$a_2 = P/P_0 = R_0/(R_0 + 2R_C) \quad [2]$$

where $R_C = Kd/S$, K is the reciprocal conductivity of ions (7), S is wafer area, and d is the distance between wafer and susceptor. Because of the linear dependence of the deposition rate on the plasma excitation power, this reduction of the excitation power is manifested through a reduction of the deposition rate of the silicon oxide film by the same factor. With only one wafer of a wafer pair insulated from the susceptor, the factor is

$$a_1 = R_0/(R_0 + R_C) \quad [3]$$

It should be stressed that the distance d between the back of a wafer and the susceptor depends on wafer flatness, roughness of the susceptor surface, etc., and thus cannot be measured easily. In fact, it should be regarded as the average distance between the wafer back side and the susceptor. However, d can be estimated from measurements of the deposition rate reductions, a_1 and a_2, at two different frequencies.

Reductions of the deposition rates of silicon dioxide films on test wafers with back sides insulated as a function of RF plasma excitation frequency are shown on Fig. 3. Depositions were performed at 125 and 100 kHz. As before, index 1 refers to depositions where one wafer of a facing pair has been insulated from the susceptor, and 2 to depositions where both have been insulated. Each point on the diagram represents the average of 3 identical depositions with 9 wafer pairs per deposition. Data suggest a frequency dependence of the reciprocal conductivity of ions K

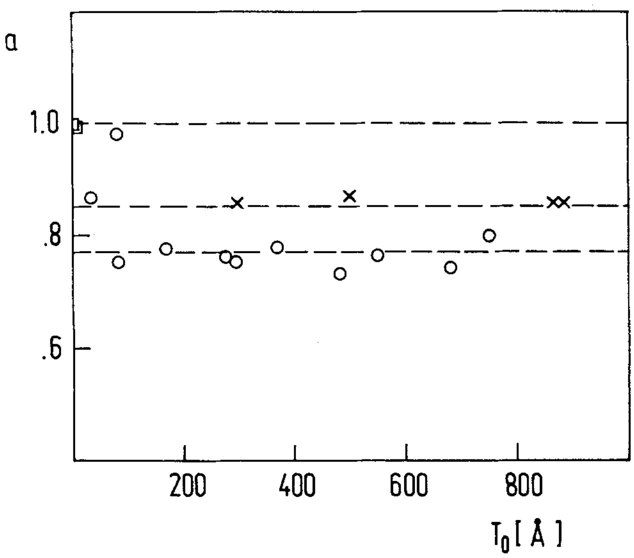

Fig. 2. Relative deposition rates of plasma silicon dioxide vs. thickness of electrically insulating thermal oxide on wafer backsides prior to plasma deposition: o—both wafers of a pair insulated, x—one wafer of a pair insulated, □—no insulating film on wafers, ν = 125 kHz.

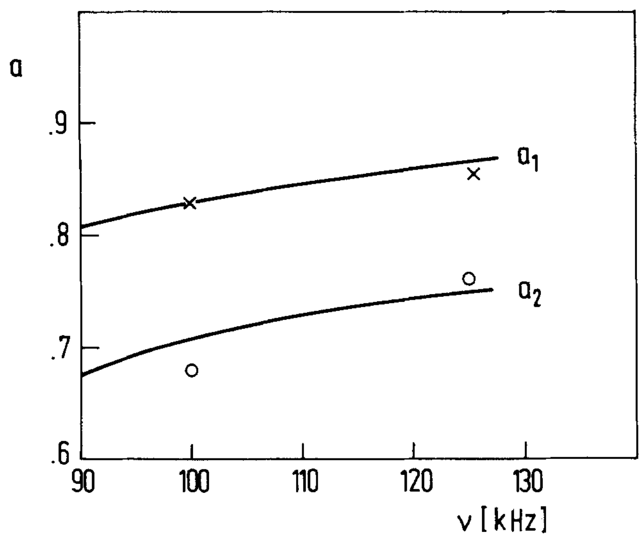

Fig. 3. Relative deposition rates of plasma silicon dioxide films at 100 and 125 kHz. Full lines represent Eq. [2] and [3]: o-both wafers of a pair insulated, x—one wafer of a pair insulated.

$$K = K'/\nu \quad [4]$$

where K' is a constant and ν the RF plasma excitation frequency. Solid ines in Fig. 3 represent Eq. [2] and [3] with this frequency dependence of K incorporated into them. Substitution of Eq. [4] into [2] and [3] allows us to estimate the value of d from the values of a_1 and a_2, and it yields $d = 0.07$ mm. This is a reasonable value for the average distance between the wafer back side and the susceptor.

Unsuccessful attempts have been made to precisely measure the deposition rate reduction factor, a_1 and a_2, at still lower RF plasma excitation frequencies. At these lower frequencies, the reduction of deposition rates on insulated wafers is even larger, but so are the influences of other rather intangible factors, such as susceptor condition, etc., controlling the deposition. The compound result is that uniformity and repeatability of depositions decrease enough to make systematic study of factors effecting the deposition rates quite unattractive.

Two conclusions regarding the uniformity of plasma depositions of silicon dioxide in reactors similar to the one used can be drawn from present stûdy.

First, it is not enough to maintain the susceptor assembly in as nearly as practically possible clean and constant condition. For maximum deposition uniformity, target wafers have to make similar electrical contact to the susceptor. In general, test wafers will not show equal deposition rates as device wafers unless they are prepared in a way that insures it, *e.g.*, by dipping them in BOE before the deposition. Under favorable conditions, uniformities can be achieved that are considerably better than those normally associated with plasma deposition and range between ±1.3 and ±3.6% for 8500Å silicon dioxide films deposited under the conditions described in the Experimental section.

Second, effectively insulating all wafers from the susceptor would eliminate the cause of nonuniform depositions, as discussed in this paper. This could be achieved, for example, by coating the susceptor with a nonconductive film that is durable enough to withstand repeated loading and unloading of wafers. A detailed study of silicon dioxide films deposited in a plasma deposition system, Applied Materials AMP 3300 Plasma II, which has the susceptor coated with ceramics, has shown no effects of wafer back side preparation on film deposition rates.

It should be noted that a 1 μm thick film of plasma silicon dioxide covering the graphite susceptor assembly does not serve this purpose. By insulting wafers from susceptor, the deposition rate of plasma silicon dioxide would be somewhat reduced.

Summary

In a vertical parallel plate plasma deposition system, deposition rates of silicon dioxide on target wafers covered with various thicknesses of insulating thermal oxide have been measured. It is shown that an insulating film on the back side of a target wafer reduces the deposition rate by approximately 25% at 125 kHz if the wafer is facing a similar one in the susceptor assembly, and by approximately 14% if the wafer it is facing has a bare silicon back side. A semiquantitative description of the effect is given, based on variations of RF plasma excitation power due to electrically insulating wafers from the susceptor. Measures to ensure uniform depositions of plasma silicon dioxide in systems under consideration are outlined.

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Electromigration Properties of Titanium/Aluminum Metallization and a Failure Mechanism for Titanium/Aluminum Gate GaAs MESFET's

Yoshinori Wada*

NTT Electrical Communications Laboratories, 3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa, 243-01 Japan

ABSTRACT

Electromigration properties of titanium and aluminum systems are studied using stripe samples. Tests are performed to determine the median failure time and standard deviation by varying the current density and ambient temperature. Next, SEM observations are made on these systems to determine the structures containing disconnections. Voids found in the Ti/Al stripes are several times larger than the voids in the Al stripes. Then, reliability tests of Ti/Al and Al gate MESFET's are carried out to determine the failure mode and distribution. These modes and distributions vary depending on the gate metallization. The differences can be explained by the electromigration properties corresponding to Ti/Al and Al metallizations.

Aluminum is one of the most common gate metals currently used in GaAs power MESFET's. However, voids near the mesa edge (1) have been reported as a failure mode for Al gate GaAs MESFET's. In addition, voids have been observed on active Al gate fingers (2).

*Electrochemical Society Active Member.

Because of these voids, gate metallization disconnection has occurred. This disconnection has caused no-pinch-off failure, where the drain current cannot decrease to the value defining pinch-off voltage. Thus, the gate metallization void is a fundamental and dominant failure mode of Al gate GaAs MESFET's. The electromigration