Dense Silicon Nitride for MMIC Protection with Low Compressive Stress Grown in LF PECVD

Willy Chiou, Brian Lee, Benny Ho, Gary Hu,C.H. Hua, D. W. Tu, Joe Liu

Win Semiconductors Corp. N 69 Technology 7th Rd, Hwaya Technology Park, Kuei Shan Hsiang,
Tao Yuan Shien, Taiwan (333)

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Abstract

We demonstrate for the first time in a high volume MMIC production line that silicon nitride protection film can be grown with LF-only plasma-enhanced CVD. The nitride film was deposited using PECVD at 250 ℃ with a compressive stress of 2.2E09 dyn/cm2 and a low BOE etching rate of 10 Å/sec. Film produced can pass the HAST (Highly Accelerated Stress Test) test with no visually detectable degradation.

I. Introduction

Silicon nitride thin film has been extensively applied to protect RF and microwave monolithic IC's against humidity, chemicals, improper handling and other environmental factors.

The stress and density of SiN film are the key quality factors in the above said application. It is widely accepted that nitride film with compressive stress and high density serves best as the MMIC final protection. The conventional wisdom requires mixed frequency (LF + HF) PECVD tool to deposit dense nitride while keeping the stress low [1]. Without investing on tooling, the target of our study is to optimize the growth condition by LF-PECVD to achieve film with low compressive stress and high density. A 4-factor 3-level DOE (Design of Experiments) is designed using the orthogonal Taguchi method.

II. EXPERIMENT

All the SiN films are prepared on 150 mm Si wafer from gas mixtures of SiH_4, NH_3 and N_2. The Trikon LF-PECVD reactor used to grow the films in this study employs conventional parallel plate design with a 13.56 MHz RF power source to generate the plasma. The wafer temperature is controlled at about 250 °C. To achieve a high yield and minimize system downtime, several features in the PECVD reactor have been implemented to maintain system cleanliness. For example, both the chamber walls and the upper gas distribution electrode of the reactor are heated to minimize particle formation during the SiN deposition process.

The four factors of this DOE are pressure, N_2 gas flow rate, NH_3/ SiH_4 gas flow ratio and RF power. TABLE I lists these factors and their associated levels.

TABLE I

FACTORS AND FACTOR RANGES FOR DOE

Factor	Value-1	Value-2	Value-3
Pressure (mTorr)	1100	800	600
NH3/SiH4 (sccm)	150/300	300/300	600/300
N2 (sccm)	2000	3000	4900
RF Power (W)	200	300	400

We characterize refractive index, deposition rate, thickness non-uniformity, stress, and wet etch rate of the grown films. A Rudolph Research model SER.7277 ellipsometer is used to determine the refractive index. Deposition rate and thickness uniformity are measured optically with a Nanometrics NanoSpec model 4150 metrology system. The thickness uniformity is defined as half the thickness range divided by the mean thickness. The thickness is measured at 9 sites across each wafer. We also use a buffered oxide etch (BOE) solution of 10:1 NH_4F : HF as the etchant in wet etch rate tests The intrinsic stress of the deposited film is determined by the standard wafer bow technique on a Tencor model FLX-2320 long scan profiler.

III. RESULTS AND DISCUSSION

A) DOE Experiment results

Figure I

SiN film stress v.s. Pressure, N2 gas flow rate, NH3/SiH4 gas flow ratio, and RF power

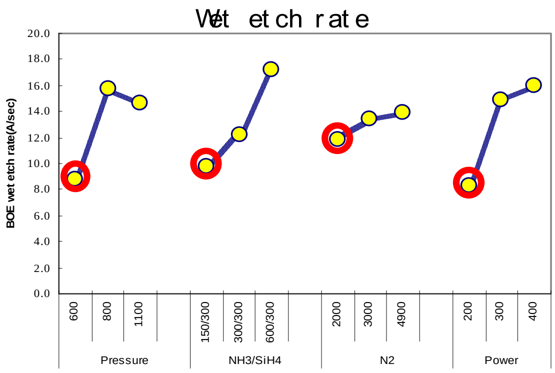

Figure II

Wet etch rate v.s. Pressure, N2 gas flow rate, NH3/SiH4 gas flow ratio, and RF power

Figures above illustrate the orthogonal analysis result. It is apparent that stress is not easily influenced by any of the four factors. On the other hand, chamber pressure, NH_3/ SiH_4 gas flow ratio and plasma RF power have significant effects on BOE wet etching rate – the best indicator for film density. In order to get denser film, pressure, power and gas flow ratio need to be lower. Following this lead, we are able to work out two optimized recipes. One of them has a compressive stress as low as 2.2E09 dyn/cm2 and BOE etching rate of 10 Å/sec. (Table II CSN-2)

B) HAST test

HAST is performed at 130℃, 85%RH, 33.3psia, for 96 hours. Pictures are taken after the test. With a thickness of 4000Å, both CSN-1 and CSN-2 show no sign of SiN defect, peeling…etc.

Table II

BEST RECIPE FORM DOE EXPERIMENT

Parameter	CSN-1	CSN-2
NH3 (sccm)	150	600
SiH4 (sccm)	300	300
N2 (sccm)	4900	4900
LF Power (W)	200	250
Pressure (mTorr)	1100	600
Temperature(℃)	250	250
Deposition rate (Å/sec)	72.0	60.5
Thickness Uniformity (%)	2.0	2.69
Refractive Index	2.12	1.81
Stress(dyn/cm^2)	3.7E09(Com)	2.2E09(Com)
Wet etch rate(Å/sec)	5.79	10.49

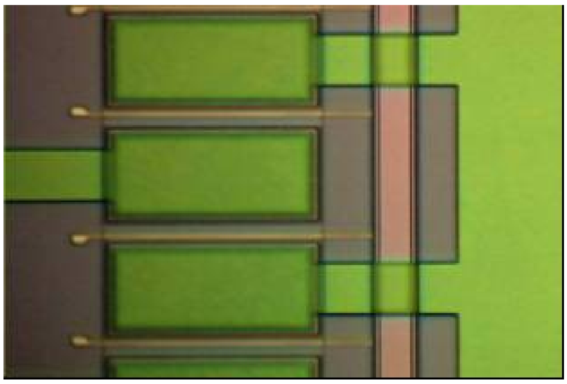

Figure III.CSN-1 4000A for protection layer, after HAST test

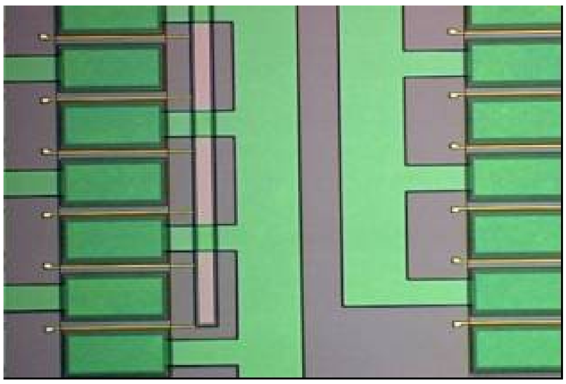

Figure IV.CSN-2 4000A for protection layer, after HAST test

IV. CONCLUSIONS

We have been able to demonstrate that low-stress dense silicon nitride is achievable using an LF-

PECVD machine in a 6” high volume production line. With no further investment on the tooling, the film qualify is no inferior to those produced by the mixed frequency PECVDs.

REFERENCES

[1] Jiro Yota, et al,2003 GaAs MANTECH Technical Digest, May 19-22,2003