Friday Morning, October 29, 1999

Plasma Science and Technology Division
Room 609 - Session PS-FrM

Emerging Plasma Applications

Moderator: W.M. Holber, Applied Science and Technology, Inc.

8:20am **PS-FrM1 Plasma Doping for Shallow Junctions**, ***S.B. Felch,*** *M.J. Goeckner, Z. Fang,* Varian Semiconductor Equipment Associates*; G.C.-F. Yeap, D. Bang, M.-R. Lin,* AMD Inc. **INVITED**

This paper reviews the characteristics of ultra-shallow junctions produced by Plasma Doping (PLAD). PLAD is one of the alternate doping techniques being developed for sub-0.18 µm devices. In the PLAD process, the substrate is placed directly in a plasma that contains the desired dopant ions. A negative-bias pulse is used to drive the dopant ions from the plasma into the substrate. Here, we describe results from a wide range of experiments aimed at the production of ultra-shallow junctions for sub-0.18 µm devices. For the results shown here, a BF@sub 3@ plasma was used to provide the dopant ions that were driven into 200-mm Si substrates using wafer biases ranging from -0.14 to -5.0 kV. The ultra-shallow junctions formed with this technique hav e been examined with both SIMS and electrical profiling techniques. Good sheet resistance uniformity, charging performance, and added contamination levels have been obtained. When PLAD is used in the production of sub-0.2 µm gate length pMOSFETs, one finds sub-threshold swing, off-state leakage, and hot-carrier reliability similar to beamline-implanted ones. In addition, higher drive currents are seen in the plasma-doped devices. These results together with the expected small footprint and low cost-of-ownership of such a system make PLAD an attractive doping technique.

9:00am **PS-FrM3 Sputter-Wind Heating in Ionized Metal PVD@footnote 1@**, ***J. Lu,*** *M.J. Kushner,* University of Illinois, Urbana

Ionized metal physical vapor deposition (IMPVD) is used to deposit seed layers and/or diffusion barriers in high aspect ratio trenches and vias for microelectronics fabrication. The physical sputtering is generated from a magnetron cathode. A secondary plasma is generated between the cathode and the substrate by an rf antenna. Experimental measurements suggest that sputter heating, generated by momentum and energy transfer from the sputtered metal atoms and the background gas atoms, rarifies the background gas and affects the transport of the sputtered atoms. In this study, sputter wind heating in IMPVD reactors is investigated using the Hybrid Plasma Equipment Model (HPEM) which has been improved to include processes relevant to sputter heating. These processes include ion energy-dependent yield, ion-energy dependent sputtered atom kinetic energy distribution, and heating due to the sputtered atoms. Improved algorithms have also been developed for electron transport in high magnetic fields to fully resolve the magnetron effect. The transport of the sputtered atoms is treated with a Monte-Carlo simulation. Statistics are collected on the interaction of sputtered atoms with the background gas, and are used to generate source terms in the continuity, momentum, and energy equations. Parametric studies have been performed for sputter heating in aluminum and copper IMPVD systems operating at low to high powers (up to 1500 W ICP, and 2000 W magnetron), and low to high reactor aspect ratio (height to radius) in 10's mTorr Ar. Due to the rarefaction in front of the target which results from sputter-wind heating, the slowing down length for sputtered atoms increases, thereby changing the flux of sputtered atoms to the substrate. Commensurate changes in the ion current to the target shift its I-V characteristics. @FootnoteText@ @footnote 1@This work was supported by SRC and TAZ.

9:20am **PS-FrM4 Opportunities and Challenges for Plasma Processes in MEMS Fabrication**, ***J.J. Sniegowski,*** Sandia National Laboratories **INVITED**

MicroElectroMechanical Systems (MEMS) are a burgeoning area of device development that has growing commercial applications in automotive, medical, and display technologies, with the promise of vigorous near-term expansion into areas such as information systems, chemical analysis, and consumer products. Microsystems present an arena for the emergence of new plasma processing techniques, especially in the demanding area of etching. Today's most prevalent IC-based fabrication method is multilayer polysilicon surface micromachining. Plasma etch processes for defining structures in surface micromachined films comprise critical fabrication steps and must evolve to enable advances in microsystem capability. Typical plasma etch processes in surface micromachining will be outlined in terms of requirements like etch profile, aspect ratio, selectivity, and etch rate for several illustrative MEMS devices. Future etch demands such as submicron spaces with aspect ratios greater than 10, polysilicon films more than 6 microns thick, and large mask open areas will be described. In fact, the needs for vertical sidewalls and simultaneous clearing of both small (1 micron) and large (>10 microns) spaces, without any micromasking, already challenge conventional plasma tools and processes. Lastly, extremely deep silicon etching for very high aspect ratio structures, or through-wafer vias for material or optical transmission, interconnect, or environmental exposure will be discussed as perhaps the most difficult task for plasma etching technology. Although the time-multiplexed "Bosch" process has been viewed as a major breakthrough for the deep silicon etch application, opportunities remain for refinements, or alternatives employing more conventional etch tools.@footnote 1@ @FootnoteText@ @footnote 1@Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract No. DE-AC04-94AL85000.

10:00am **PS-FrM6 200 mm SCALPEL@super TM@ Mask Dry Etch Development**, ***G.R. Bogart,*** *A. Kornblit,* Lucent Technologies*; I. Johnston,* Surface Technology Systems, UK*; A.E. Novembre, M.L. Peabody, C.S. Knurek, R.J. Kasica,* Lucent Technologies

SCALPEL (SCattering using Angular Limitation Projection E-beam Lithography) is based on the variation in scattering angles between two electron transparent materials supported on a membrane mask.@footnote 1@ Plasma etching of the membrane structure offers many advantages over wet etching using KOH. We have used a Time Multiplexed Deep Etching (TMDE) technique (Bosch process)@footnote 2,3@ for generation of large area thin (200:1 with a side wall angle of 89°. Etch uniformity is

10:20am **PS-FrM7 High Anisotropy Etching of 0.18 Micron Platinum Electrodes**, ***S.D. Athavale,*** *D.E. Kotecki,* IBM, Microelectronics Division*; H. Shen,* Siemens*; J. Hwang, C. Ying, D.J. Lee, S. Mak,* Applied Materials, Inc.

Platinum is one of the most promising electrode materials for future high density DRAM capacitors based on high dielectric constant materials such as BST. Achieving veil-free, vertical sidewall profiles, when dry etching platinum, has remained an elusive goal due to the low volatility of etch-products under traditional plasma etching conditions. We have studied etching of platinum using a high-density plasma reactor equipped with a high temperature (>200°C) cathode. Statistical design of experiments (DOE) methodology was used. It has been found that the result of etching Pt is strongly influenced by the wafer temperature. For example, increasing the wafer temperature leads to a dramatic increase in the Pt etch rate and a change in resulting Pt profile. Nearly vertical sidewall profiles (89°) and veil-free Pt etching results are achieved on 0.18µm electrode. The key wafer-level issues and integration challenges associated with the etching of Pt electrodes under high temperature conditions are also discussed.

10:40am **PS-FrM8 Real Time Control of Plasma Tools During Recipe Changes and Transients@footnote 1@**, ***M.J. Kushner,*** University of Illinois, Urbana*; S. Rauf,* Motorola Inc.

Successful development of real time control (RTC) of plasma tools should enable more rapid process development. A full etch process often includes multiple recipe changes to optimize, for example, break-through, main etch and over-etch. If the recipes are markedly different in gas composition or pressure, process parameters such as uniformity may significantly change during the transient. In the absence of RTC, maintaining desired process parameters requires changes in actuators based on interpolation between the beginning and end conditions. In this paper, the Virtual Plasma Equipment Model (VPEM) is used to investigate RTC strategies during recipe changes and transients. The VPEM is a "wrapper" for the Hybrid Plasma Equipment Model which contains simulated sensors, controllers and actuators. Recent improvements in the VPEM allow investigation of "real-time" (as opposed to run-to-run) control. Results from the VPEM will be discussed using response-surface based controllers to maintain process uniformity and rate during recipe changes for Cl@sub 2@ and C@sub 2@F@sub 6@ chemistries in ICP reactors. It was found that during recipe changes which, for example, significantly change mole fractions, the linearized response surfaces based on conditions at any given mole fraction are not adequate. Control is maintained for a portion of the transient but is eventually lost. To address this problem, real time mass spectrometer sensor data is used to interpolate between response surfaces which are the basis of (2 x 2) controllers. The response surfaces were generated using results from steady-state experiments. This strategy was able extend the dynamic range of control throughout the transient. @FootnoteText@ @footnote 1@This work was supported by AFOSR/DARPA, SRC and LAM Research.

11:00am **PS-FrM9 Plasma Injection with Small Helicon Sources*, F.F. Chen,*** University of California, Los Angeles*; X. Jiang,* Broadcom, Inc.

Distributed plasma sources for large-area etching and deposition, comprising multiple helicon injectors, have been shown to be feasible.@footnote 1@ In this experiment, we studied the coverage provided by a single small source, varying the magnetic field and antenna configurations. The source was a 2.2 cm i.d., 12 cm long pyrex tube tightly covered by a thin, 3.9 cm i.d. solenoidal magnet coil providing up to a B = 100G field. A helical antenna was normally used to launch right-hand circularly polarized waves with 0-1000 W of 13.56 or 27.12 MHz power. The argon plasma was injected into to a 30 cm diam chamber with or without a permanent magnet "bucket". The low-field density peak@footnote 2@ usually found in helicon sources was not seen; instead, the maximum density almost always occurred at B = 0, as in ordinary ICPs. However, the densities were in the 10@super 11-12@ cm@super -3@ range characteristic of helicon sources. These were indeed helicon discharges, and the absence of a low-field peak was explained by detailed mapping of the magnetic field. With close-fitted solenoids, the plasma created near the edge of the source was scraped off by the entrance flange or was brought back to the top plate once the magnetic field became strong enough to entrain the electrons. At the higher fields, only the plasma created near the axis was available to a downstream probe. The high efficiency of helicon sources can be made available by properly designing the magnetic field coils so that all the field lines reach the interior of the downstream region and then diverge before striking the substrate. @FootnoteText@ @footnote 1@F.F. Chen and J.D. Evans, Proc. Plasma Etch Users Group (NCCAVS, 150 W. Iowa Ave., Suite 104, Sunnyvale, CA 94086) (1998). @footnote 2@F.F. Chen, J. Vac. Sci. Technol. A 10, 1389 (1992). .

11:20am **PS-FrM10 Ultra-Low-Temperature Formation of Silicon Nitride Gate Dielectric Films by Novel Plasma Technique*, M. Hori,*** *H. Ohta, A. Nagashima,* Nagoya University, Japan*; M. Ito,* Wakayama University, Japan*; T. Goto,* Nagoya University, Japan

As device dimensions shrink below 100nm in ULSI, the thickness of gate dielectric film (SiO@sub2@) in FETs will fall to be 2-3nm range. The SiO@sub2@ film is replaced by a dielectric film with a higher dielectric constant film. In this study, we have successfully formed the ultra thin silicon nitride (SiN@subx@) films of 5nm in thickness at a low temperature of 300 degree C by the novel plasma technique using ECR SiH@sub4@/N@sub2@ plasma enhanced CVD (PECVD), where the charged species incident on the substrate were removed by two permanent magnets set above the substrate. It enabled us to form SiN@subx@ films by only neutral radicals. The experimental conditions were 0.5Pa, 300W, SiH@sub4@/N@sub2@ of 5/100sccm, and a substrate bias of floating. The films indicated the low leakage current of 7x10@super-8@A/cm@super2@ at 3MV/cm, dielectric constant of 7.3 and near stoichiometry composition. The reaction mechanism of film deposition with and without charged species were investigated by in-situ XPS and in-situ FT-IR reflection absorption spectroscopy. In the case of without charged species, two absorption bands ascribed to Si-N stretching mode at 970cm@super-1@ and 1085 cm@super-1@ were observed. The low frequency component is probably due to the metastable layer and the high one is due to the SiN@subx@ network. On the other hand,with charge species, the only low component was observed. The metastable layer is considered to cause the degradation of electrical properties of films. On the basis of these results, the control of ion bombardment on the growth was found to be a key factor for forming ultra thin SiN@subx@ films of high quality at a low temperature in PECVD.

11:40am **PS-FrM11 Characterizations of a Compact, Low-Field Toroidal Plasma Source for Downstream Plasma Processing*, X. Chen,*** *W.M. Holber, D.K. Smith,* Applied Science and Technology, Inc.*; M.G. Blain, R.L. Jarecki,* Sandia National Laboratories

Activated atomic gases are used in semiconductor processing for applications including photoresist strip, passivation and chemical vapor deposition (CVD) chamber clean. We report the production of activated atomic fluorine, oxygen, nitrogen and hydrogen using a low-field toroidal (LFT@super TM@) downstream plasma source. The ASTRON@super TM@ reactive gas generator uses an electrodeless toroidal plasma source design, in which the rf power supply is integrated directly into the same enclosure as the plasma source. It operates at pressures from a few millitorr to one atmosphere. Typical plasma density is 3x10@super 13@ cm@super -3@. Thorough characterization of the plasma source is conducted using working gases such as NF@sub 3@, CF@sub 4@, CHF@sub 3@, C@sub 3@F@sub 8@, SF@sub 6@, O@sub 2@, N@sub 2@, NH@sub 3@ and H@sub 2@. The production and transport of the atomic species are investigated using chemiluminescent titration and etch rate measurements of silicon dioxide and photoresist. Greater than 90% of NF@sub 3@ is dissociated at flow rates of over 2 slm. The etch rates of SiO@sub 2@, SiN, WN, W and TiN are measured. Adding argon to an O@sub 2@/N@sub 2@ plasma increases the production of atomic oxygen and the rate of photoresist strip while not raising the power consumption. Contamination and particle measurements show that the plasma source is compatible with semiconductor processing. @FootnoteText@ Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract No. DE-AC04-94AL85000.

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