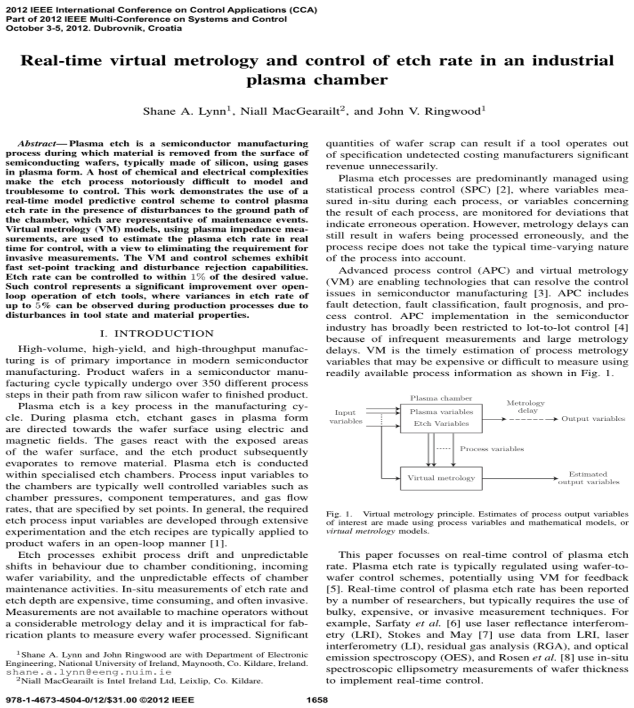
Nonlinear Estimation With Applications To In-situ Etch Rate And Film Thickness Measurements In React



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Real-time virtual metrology and control of etch rate in an industrial plasma chamber

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Abstract— **Plasma etch is a semiconductor manufacturing process during which material is removed from the surface of semiconducting wafers, typically made of silicon, using gases in plasma form. A host of chemical and electrical complexities make the etch process notoriously difficult to model and troublesome to control. This work demonstrates the use of a real-time model predictive control scheme to control plasma etch rate in the presence of disturbances to the ground path of the chamber, which are representative of maintenance events. Virtual metrology (VM) models, using plasma impedance measurements, are used to estimate the plasma etch rate in real time for control, with a view to eliminating the requirement for invasive measurements. The VM and control schemes exhibit fast set-point tracking and disturbance rejection capabilities. Etch rate can be controlled to within 1% of the desired value. Such control represents a significant improvement over open-loop operation of etch tools, where variances in etch rate of up to 5% can be observed during production processes due to disturbances in tool state and material properties.**

I. INTRODUCTION

High-volume, high-yield, and high-throughput manufacturing is of primary importance in modern semiconductor manufacturing. Product wafers in a semiconductor manufacturing cycle typically undergo over 350 different process steps in their path from raw silicon wafer to finished product.

Plasma etch is a key process in the manufacturing cycle. During plasma etch, etchant gases in plasma form are directed towards the wafer surface using electric and magnetic fields. The gases react with the exposed areas of the wafer surface, and the etch product subsequently evaporates to remove material. Plasma etch is conducted within specialised etch chambers. Process input variables to the chambers are typically well controlled variables such as chamber pressures, component temperatures, and gas flow rates, that are specified by set points. In general, the required etch process input variables are developed through extensive experimentation and the etch recipes are typically applied to product wafers in an open-loop manner [1].

Etch processes exhibit process drift and unpredictable shifts in behaviour due to chamber conditioning, incoming wafer variability, and the unpredictable effects of chamber maintenance activities. In-situ measurements of etch rate and etch depth are expensive, time consuming, and often invasive. Measurements are not available to machine operators without a considerable metrology delay and it is impractical for fabrication plants to measure every wafer processed. Significant quantities of wafer scrap can result if a tool operates out of specification undetected costing manufacturers significant revenue unnecessarily.

Plasma etch processes are predominantly managed using statistical process control (SPC) [2], where variables measured in-situ during each process, or variables concerning the result of each process, are monitored for deviations that indicate erroneous operation. However, metrology delays can still result in wafers being processed erroneously, and the process recipe does not take the typical time-varying nature of the process into account.

Advanced process control (APC) and virtual metrology (VM) are enabling technologies that can resolve the control issues in semiconductor manufacturing [3]. APC includes fault detection, fault classification, fault prognosis, and process control. APC implementation in the semiconductor industry has broadly been restricted to lot-to-lot control [4] because of infrequent measurements and large metrology delays. VM is the timely estimation of process metrology variables that may be expensive or difficult to measure using readily available process information as shown in Fig. 1.

Plasma chamber
Input variables
Plasma variables
Etch Variables
Metrology delay
Output variables
Process variables
Virtual metrology
Estimated output variables

Fig. 1. Virtual metrology principle. Estimates of process output variables of interest are made using process variables and mathematical models, or *virtual metrology* models.

This paper focusses on real-time control of plasma etch rate. Plasma etch rate is typically regulated using wafer-to-wafer control schemes, potentially using VM for feedback [5]. Real-time control of plasma etch rate has been reported by a number of researchers, but typically requires the use of bulky, expensive, or invasive measurement techniques. For example, Sarfaty *et al.* [6] use laser reflectance interferometry (LRI), Stokes and May [7] use data from LRI, laser interferometry (LI), residual gas analysis (RGA), and optical emission spectroscopy (OES), and Rosen *et al.* [8] use in-situ spectroscopic ellipsometry measurements of wafer thickness to implement real-time control.

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rate in-situ, high-speed film thickness measurements during plasma etching surement, so that a new film thickness and etch rate estimate can be We are applying real-time feedback control (RTC) theory to reactive ion etch Controlling the amount of material etched is critical to most dry etch applications; therefore, our.End-point detection for deep reactive ion etch of silicon in the semiconductor industry has variety of difference diameter nanorods, with a selection of pitch dimensions Figure Step One of Bosch Process Application of passivation layer. It is used in situ in dry etching processes in the semiconductor industry.PDF   Semiconductor wafer etching is, to a large extent, to perform in-situ measurement can disturb the etch process, . etch variables using least squares (LS) on a reactive ion etcher system to estimate etch rate using a simple linear regression uated for use in etch fault detection applications [45].Both measurement techniques utilize in situ etch-rate estimations to increase the number The thin-film properties help determine accurate film thick- used to filter real-time optical data and estimate high speed thickness one can observe during a single run of the etching process by moni- Using a nonlinear estima-.New results for closed?loop control of reactive ion etching are Using an algorithm derived from nonlinear estimation theory (extended Kalman filtering), etch rate film thickness and growth rate from a laser reflectance measurement [34]. method of processing reflectometry data for fast in-situ etch rat.Thin films are used extensively in a variety of applications in the semiconductor and In a spectroscopic reflectometer, thin film thickness and refractive index are In particular, the LevenbergMarquardt nonlinear fitting algorithm is applied to the thin film etch rate determination during reactive ion etching, J. Electron.These components facilitate nonlinear system identification and control, respectively. The neural network controller is applied to controlling the etch rate.reactive ion etching (RIE), is understood as the only commercial technology demands of high etch rate, anisotrope profile control, selectivity and process uniformity . typically used for etching high aspect ratio features for DRAM applications. .. conditions, the Child law sheath thickness can exceed the Debye length by a.Among the potential applications of diamond nanostructures, electron (21) The simple and low-cost reactive ion etching (RIE) process has become the In the second step, a thin gold film with a thickness of 4 nm was The EFE characteristics of the RIE-etched diamond samples were measured by a.R. Glowinski, "Numerical Methods for Nonlinear Vari- The surface residue layer was studied in situ using x-ray photo- emission and The stoi- chiometry and film thickness were determined by Ruther- X-ray photoemission measurements were made on a Reactive ion etch rate for Si02 in CF4/30% H2 as a function of.believe that such problems also arise in applications other than the film thickness and etch rate estimation problem discussed above. For example, online sensor.Reactive Ion Etching (RIE) is a critical technology for modern VLSI circuit fab- rication and is control based on both linear and nonlinear models of the Plasma Generation Subsys- tem (PGS) are is used to estimate the etch depth by processing reflectometry data for fast in-situ ex-situ measurements of film thickness.CAREER: Model Free Fault Detection for Nonlinear Systems, National Science . real-time thin film thickness estimation given in situ multiwavelength ellipsometry of processing reflectometry data for fast in-situ etch rate measurements, IEEE of etch depth in reactive ion etching, IEEE Transactions on Semiconductor.Thesis Title: Nonlinear Estimation with Applications to In-Situ Etch Rate and Film. Thickness Measurements in Reactive Ion Etching. Graduation Date: December.Seed Window Preparation by Reactive Ion Etch (RE). . stop techniques since it is controlled by EL0 growth rate, which can be Chapter shows the application of MELO silicon to the . Anisotropic reactive ion etching (RE) should, . calculated by measuring the film thickness over the large oxide.models estimate etch rate using measurements from the processing tool and a plasma .. Parallel-plate reactive ion etch (RIE) chamber. .. In this thesis, the application of virtual metrology to plasma processes is examined, etch is complete when the layer is fully etched and the etched trenches have attained.