TCP Machine Fault Detection in Etch Based on Broadband RF Signal Observation

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Abstract

A novel broadband RF sensor is used for machine fault detection on a high density poly-Si etcher. The major sensors on the etching system measure transformer-coupled power (TCP), bias power, pressure, and gas flow rates. A broadband RF sensor is used to detect and identify errors in the machine sensors due to drift or miscalibration. The work presented here focuses on detecting errors in the TCP measurement, though the method has potential for several of the other sensors. For a main etch process on a Lam 9400SE, ± 12 % relative deviations in TCP measurement can be detected with 95 % error detection rate and a false alarm rate of less than 5 %.

Introduction

An early and accurate detection of a machine fault is critical to decreasing semiconductor device production cost and to shortening the manufacturing cycle [1]. A total machine part failure is often easy to detect by visual inspection. However, unlike a mechanical part failure, a partial sensor failure poses a much more difficult problem. An unobserved drift in the deposited power, chamber pressure, or gas flow rates can significantly impact the etch process, yet it is much more difficult to detect and identify the source of such variations. This paper investigates the use of a broadband Radio Frequency (RF) sensor [2] to detect changes in the deposited TCP power in a poly-Si main etch on an Lam 9400SE. The distinctive RF fingerprint of the process from the broadband sensor is rich enough to distinguish plasma variations due to faults in the measurement of TCP power from variation in the outputs of the remaining sensors.

Experimental Detail

A. *Experimental Setup*

This research was conducted using a low-pressure, high-plasma density Lam 9400SE plasma etching system and an in-house-constructed broadband RF sensor [2]. The RF sensor consists of a 2.54 cm long tungsten probe tip inserted in an aluminum cylinder and contained in a quartz tube. The tube was placed inside the etcher, but not physically touching the plasma. A Hewlett Packard 8753B Vector Network Analyzer was used to measure the complex reflection coefficient, Γ. The HP network analyzer swept a wide 0.5–2.5 GHz range of frequencies and collected 201 data points of log magnitude of the reflection coefficient, $\log(\Gamma)$, and its phase, $\arg(\Gamma)$, at a 5 Hz sampling rate. Other important signals, including TCP and bias powers (W), pressure (mTorr), and gas flow rates (sccm), were collected at a 20 Hz sampling rate and subsequently used for in the fault detection analysis. A 6-inch poly-Si wafer was etched under the Main Etch (ME) condition which uses Cl_2 and HBr gas. The native oxide layer on the wafer was removed before the ME by 15 sec of C_2F_6 based Break Through (BT) etch [3].

B. *Design of Experiment*

In order to collect the RF fingerprint under various sensor error situations and build a fault detection model, the following experiment was performed on the Lam 9400SE. It was assumed that the machine faults occur one at a time, so the five machine input variables, TCP and Bias power, pressure, and Cl_2 and HBr flow rates, were changed one at a time from their nominal values. The resulting broadband RF signal was then collected during the etch. TCP and Bias power, and HBr flow rate were changed ± 10 % and ± 25 % from their nominal values of 250 W, 180 W, and 75 sccm, respectively. Since the pressure and Cl_2 flow rate settings are relatively small values, 10 mTorr and 15 sccm, respectively, their nominal values were changed by ± 20 % and ± 40 %. For model validation, the pressure and Cl_2 flow rates were changed by ± 30 %, and the TCP and Bias power, and HBr flow rate were changed by ± 15 %.

Experimental Result

Fig. 1 shows a typical response of the broadband RF sensor for a variation in TCP. Two things can be noted: there are two dominant peaks in the reflection coefficient for each power setting, and there is a very nearly linear increase in the peak frequencies with TCP. A single sweep of sors. Following [1], as a first step in data reduction, an RLC circuit parameterization of the RF response was performed. Each peak of the RF response was modeled as a series RLC circuit. This reduces the 402 data points to 6. Also following [2], in the parameterizaztion of the RLC circuit models, the natural frequency, ω_n, and the quality factor, Q, were used instead of L, and C.

Next, a regression model of TCP centered about its nominal value was determined as a function of the measured RF values. As shown in Fig. 2, $\omega_{n2} - \omega_{n1}$ is very nearly linear with TCP indicating a strong candidate for TCP estimation. A regression model was determined to be

$$\begin{aligned} \widehat{\mathrm{TCP}} &= -58.0 + 0.0120\mathrm{Bias} * \mathrm{Pressure} \\ & -0.0017\mathrm{Bias} * \mathrm{HBr} + 100.913(\omega_{n2} - \omega_{n1}) \end{aligned} \quad (1)$$

with R^2=0.9938. A TCP fault was declared if

$$\frac{|\widehat{TCP} - TCP_{nom}|}{TCP_{nom}} > \gamma \quad (2)$$

where TCP_{nom} is nominal TCP power (250 W), and γ is a threshold to be determined.

The probability of a fault occurring was assumed to be 10^{-4}. Furthermore, faults in individual sensors were assumed to be mutually exclusive, and equally likely. Given that a fault has occurred in a particular sensor, the probability distribution function (pdf) of the corresponding machine state was assumed to be uniformly distributed over the range of values covered in the DOE. With this model, the threshold γ was varied from $0 < \gamma \leq 0.25$. Fig. 3 and 4 illustrate the Receiver Operating Characteristic (ROC) of the proposed fault detection method. It demonstrates 95 % TCP fault detection probability with 5 % false alarm probability when TCP has $\pm$ 12 % deviation in TCP.

The work presented here focuses on detecting errors in the TCP measurement, though the method has potential for several of the other sensors and will be presented.

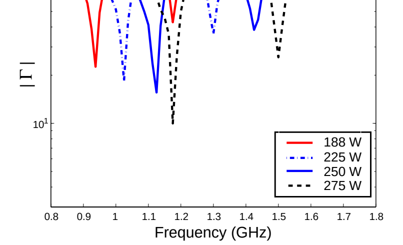

Fig. 1. **RF signal variation with TCP.**

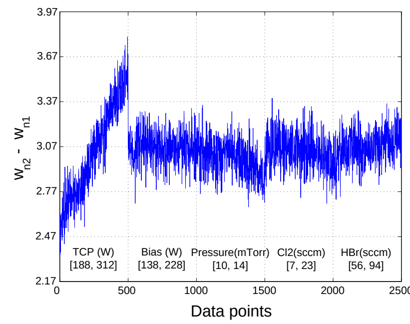

Fig. 2. $\omega_{n2} - \omega_{n1}$ **(GHz) variation with various machine input changes. Each 500 data points were interpolated from the DOE data.**

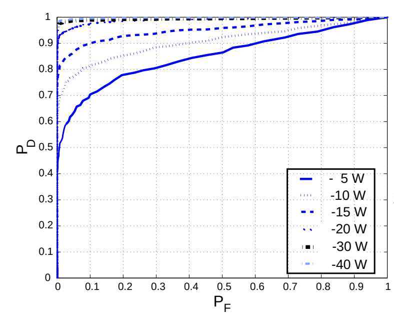

Fig. 3. **Receiver Operating Characteristic (ROC) of TCP error detection with TCP estimation. Legend shows the deviation from its nominal value, 250 W.**

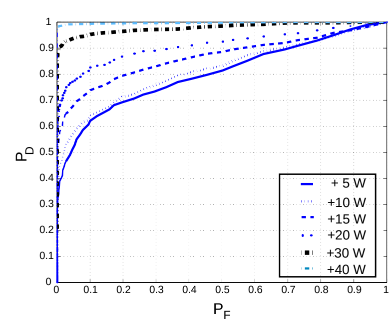

Fig. 4. **Receiver Operating Characteristic (ROC) of TCP error detection with TCP estimation. Legend shows the deviation from its nominal value, 250 W.**

References

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