

Multivariate Endpoint Detection of Plasma Etching Processes

By Brian E. Goodlin

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Abstract

In plasma etching processes it is critical to know when the film being etched has cleared to the underlying film, i.e. to detect endpoint, in order to achieve the desired device performance in the resulting integrated circuit. The most highly utilized sensor technology for determining endpoint has historically been optical emission spectroscopy (OES), because it is both non-invasive and highly sensitive to chemical changes in the reactor. Historically the intensity of one emission peak corresponding to a reactant or product in the etch process was tracked over time, leading to a step change that is detectable in the optical emission endpoint trace for many plasma etching processes. Unfortunately, for several critical etching steps (contact and via), the exposed area of the film being etched is very low (<1%, with the rest being masked with photoresist), and this traditional method of endpoint detection has failed because of the low signal-to-noise ratio at endpoint. Our work has provided a way to improve the endpoint sensitivity by a factor of approximately 5-6, so that endpoint can be adequately detected for these low area etching steps. By utilizing CCD array detection for OES sensors, it is possible to rapidly collect (2-10 Hz) full spectral data (200-900 nm in wavelength), consisting of over 1000 discrete wavelength channels from a plasma etching process. By appropriately utilizing this multi-wavelength data, we have been able to achieve significant improvements in sensitivity. Our work has focused on characterizing, analyzing and developing new multivariate (multi-wavelength) strategies to optimize the sensitivity of the endpoint detector.

This thesis provides a thorough comparison of several different multivariate techniques for improving endpoint detection sensitivity and robustness, both experimentally and theoretically. The techniques compared include: 1) multivariate statistical process control metrics such as Hotelling's T^2 ; 2) chemometrics techniques such as principal component analysis (PCA) and T^2 and Q statistics based on PCS, evolving window factor analysis (EWFA); 3) discriminant analysis; and 4) a new methodology called the Multi-wavelength statistic weighted by Signal-to-Noise ratio or MSN Statistic. A quantitative methodology based on signal-to-noise analysis was employed to compare the various techniques. Following this type of analysis, the MSN statistic was developed to provide theoretically the optimal improvement in endpoint detection sensitivity given certain assumptions about the nature of the noise in the data. Applying the MSN statistic to experimentally collected endpoint data confirmed that it did give superior results. By utilizing information about the direction (in the multivariate space) of endpoint from prior runs, the MSN statistic showed significant improvement over the traditional multivariate T^2 statistic, that does not use any prior knowledge for detection.

Another important aspect of the work was in characterizing the nature of multivariate noise, and understanding how different multivariate algorithms treat the different forms of

multivariate noise. In general we found that multivariate noise could be broadly classified into two components: 1) uncorrelated noise across the different wavelength channels that was mostly due to photon shot noise at the CCD array sensor; and 2) correlated noise that was mostly due to variations in the plasma etching process, such as fluctuations in power, pressure, and flow rates of the gases in the reactor. For a given etch process, we have created a novel way to characterize how much noise is correlated and uncorrelated. The removal of these two components of noise required very different mechanisms, namely *noise reduction* for reducing the uncorrelated noise component and *disturbance rejection* for removing the correlated noise component.

The reduction of the uncorrelated noise is obtained by partial cancellation of noise when summed together. The disturbance rejection involved the isolation of the correlated process disturbance along a particular direction(s) in the multivariate space, leaving the residual space for endpoint detection. The different multivariate algorithms can be classified according to their ability to do either disturbance rejection, noise reduction or both. Additionally we have found that time-averaging filters can also be employed to provide both disturbance rejection and noise reduction. By thorough analysis of the nature of the noise, we were able to create an optimal strategy that utilized time-averaging filters combined with multivariate statistics to achieve significant improvements in endpoint detection sensitivity.