Multivariate Endpoint Detection for Plasma Etching Processes

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Sponsorship

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Endpoint detection has been used for many years to improve control over plasma etching processes. The most common sensor technology for determining endpoint has been optical emission spectroscopy, because it is both non-invasive and highly sensitive to chemical changes in the reactor. The intensity of one emission peak corresponding to a reactant or product peak is typically tracked over time, leading to a single-wavelength endpoint trace like those shown in Figure 1. Unfortunately, for low open area etches (<1%) including contact and via etches, tracking individual wavelength intensities has been unsuccessful because of the low signal-to-noise ratio at endpoint. Figure 1 demonstrates adequate endpoint for 100% and 10% open area etches, but not for 1% open area etches. Recently, multi-wavelength or multivariate approaches to endpoint detection are becoming commercially available. These techniques make use of full spectral data (200-900 nm) that can be collected across 1000 or more discrete wavelength channels at data collection rates of 2-10 Hz. Our work has focused on characterizing, analyzing, and developing multivariate algorithms for improving sensitivity of endpoint detection. Through detailed understanding of the nature of the noise and application of an optimal multivariate method, improvements in sensitivity by a factor of 5-6 over the single-wavelength method are achieved for a typical plasma etching process. This is shown pictorially for a 0.5% open area case in Figure 2. The optimal methodology requires an appropriate combination of digital signal processing combined with multivariate data analysis to maximize the reduction of noise coming from the process and the sensor.

Our work compares several different multivariate techniques for improving endpoint detection sensitivity and robustness, both experimentally and theoretically. Fundamentally, most of the improvement is gained through one of two mechanisms: 1) isolating and rejecting correlated process disturbances such as thermal drift or window clouding, or 2) reducing uncorrelated sensor noise (primarily photon shot noise). Isolation of the process disturbance can be done in either the time domain, by appropriate frequency filtering usually in the form of a derivative, or in a multivariate spectral space, by rotation of spectral data through principal component analysis. The reduction of uncorrelated noise is obtained through partial cancellation of uncorrelated noise that is summed together, either using a smoothing filter in time or with a multivariate algorithm. The optimal methodology for sensitivity and robustness ultimately utilizes a frequency filter to remove the process disturbance and an optimally weighted linear combination, called the MSN statistic, to provide the best reduction in noise. This approach proves superior to the traditional multivariate statistical process control approach and to the single wavelength methodology that is currently used.

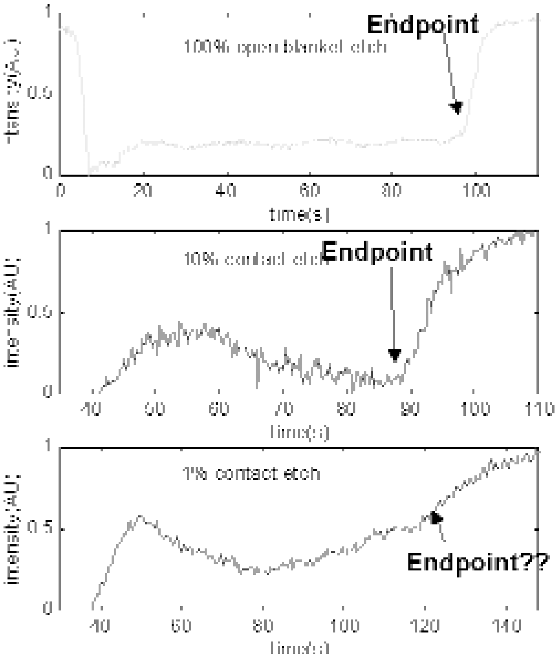

Fig. 1: Plot of single wavelength endpoint traces for three separate open areas (100%, 10%, 1%). Single wavelength methodology does not work well for 1% contact etch.

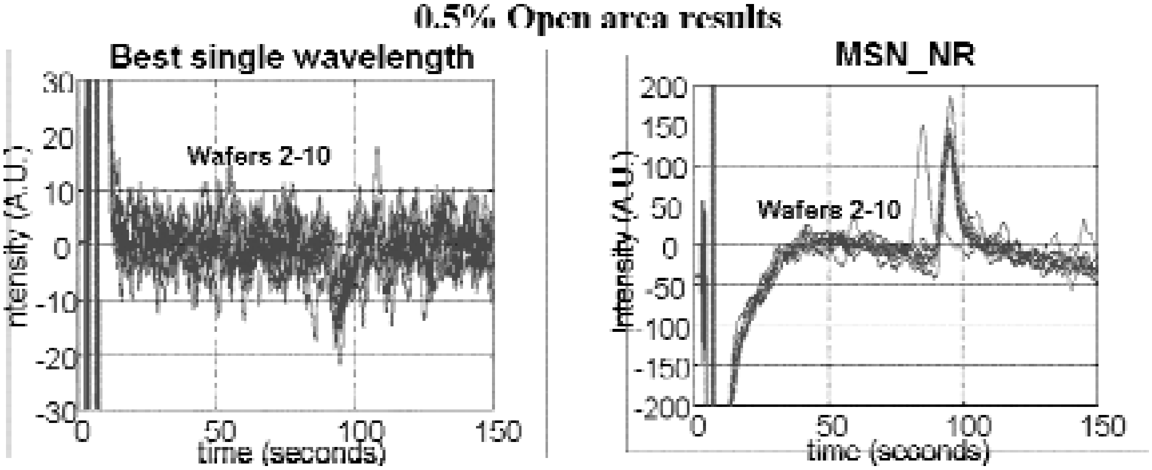

Fig. 2: Comparison of the most sensitive single wavelength endpoint trace (left) with the optimal multi-wavelength endpoint trace (right) for nine consecutive wafers, revealing substantial improvement in endpoint detection sensitivity.