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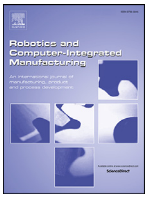

Real-time plasma monitoring technique using incident-angle-dependent optical emission spectroscopy for computer-integrated manufacturing

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ABSTRACT

Although various monitoring techniques are currently used for semiconductor manufacturing, OES is a non-contact and non-destructive plasma measurement tool that detects end points and plasma abnormality. Despite these advantages and their high utilization in plasma processing measurement, the acquisition region of OES data at various wafer sizes only allows examination of part of the plasma, owing to the characteristics of the conventional OES resulting in the limited detection capability of process abnormality. In this paper, a novel real-time monitoring method for detecting plasma process uniformity and abnormality using incident-angle-dependent OES is proposed. Using both a body tube and a wide-angle lens to adjust the incident angle of OES, the intensity of plasma light can be measured accurately using selective plasma light in semiconductor manufacturing. This real-time monitoring technique can be utilized to obtain plasma light in a process chamber and thereby analyze the uniformity and detect the abnormalities in the plasma process for computer-integrated manufacturing.

1. Introduction

Nowadays, semiconductor manufacturing industry is forwarded to the high-volume manufacturing that produces large quantities of chips through unmanned factory automation. For factory automation, it is necessary that real-time monitoring technique can detect and monitor process abnormality during production which severely impacted on yield and cost. Therefore, the semiconductor manufacturing industry needs real-time abnormality monitoring system to improve interruptions of factory automation through additional low-cost instrument equipment with easy installation during the processing [1,2]. However, among conventional real-time monitoring techniques, some conventional monitoring techniques are less accurate or in adequate. For example, although residual gas analyzer is widely used, this technique is difficult to install the exhaust line of a process chamber and measure the gas ratio accurately because they are located away from a process chamber. Thus, the plasma contact technique is developed to measure plasma characteristics directly because this sensor is located near upper electrode and sidewall of process chamber [3,4]. However, this technique is not widely used because of high price and installation complexity.

Among semiconductor manufacturing processes, photolithography is the most important technology because of improvements in semiconductor integration and large wafer size [5–10]. However, due to limitations in technology, the recent technical progress in photolithography has been slow [11–13]. Therefore, dual patterning technology and quadruple patterning technology using a 193 nm ArF laser are used instead of EUVs [6]. Because of this, the number of required etching and chemical vapor deposition (CVD) processes is dramatically increased with the number of layers of photolithography processes [14–18]. This leads to growth in the number of tools for etching and CVD, leading to increased probability of process abnormality and the need for process monitoring. Plasma abnormality in etching process affects un-etched or over-etched patterns. In CVD, this abnormality causes non-uniformity in deposition. Thus, if wafer rework or scrap is available to detect all plasma abnormalities by OES during processing, this technique contributes the reduction of production tool loss as well as semiconductor unmanned manufacturing enhancement. As the number of plasma etching and deposition processes increases, the demands for plasma monitoring techniques from industry such as Samsung and TSMC, are also increased and developed [1,2,16,18–35]. However, only a few plasma monitoring tools and techniques have been developed to date [1,2,16,22–26].

Etching and CVD use plasma sources for precise processing. The purpose of plasma monitoring technique is to detect real-time plasma abnormalities during the processing to enhance yield and productivity. These techniques are also available to analyze plasma chemistry and plasma physics. These techniques can be classified into *in-situ* and *ex-situ* measurement techniques [25,26]. Probes and residual gas analyzers without optical emission spectroscopy (OES) have disadvantages because of their installation complexity and high cost [20]. However, OES is widely

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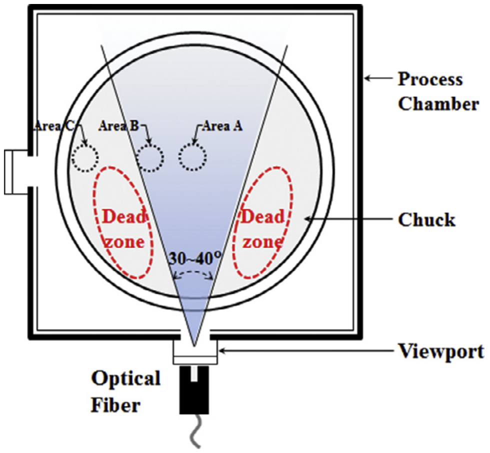

Fig. 1. Schematic of the incident angle of conventional OES and the measurable region of light in a process chamber.

used to determine abnormal situations within the process chamber, such as endpoint and arcing, thanks to its easy installation and non-invasive process. This method involves the use of a spectral apparatus for measuring the intensity of light at different wavelengths, and its principle is very simple. Plasma light enters the viewport of a process chamber and its intensity is measured via OES apparatus [36].

Although the OES apparatus can be easily mounted without affecting the fabrication of chips, OES has one technical limitation. As shown in Fig. 1 it cannot differentiate lights from local areas such as area A, area B and area C, since the optical fiber of OES has a specific measurable range [37]. Using the principle of superposition of light, the spectroscope sums the plasma light directed toward the optical fiber within a specified angle. In general, the light is acquired at incidence angles of 30–40°, and, thus, OES data may be affected by plasma abnormality [37,38]. It is difficult to detect abnormalities such as arcing or plasma flickering in the process chamber because of the ambiguous angles in a conventional OES system. Thus, in order to address this problem, proper incident angle adjustment is required.

In this paper, to enhance real-time process monitoring technique for semiconductor manufacturing automation, the real-time monitoring schemes for plasma process using OES are proposed and experimented. A body tube for a narrower incident angle and a wide-angle lens for a wider incident angle are designed to adjust the measurable range of the optical fiber. After analyzing the measurement characteristics of a conventional OES system and its drawbacks in terms of the incident angle, an optimum incident angle for OES is proposed to improve the accuracy of plasma abnormality monitoring and detection capability. Based on the results of this work, a scheme to improve conventional OES is proposed to enhance real-time plasma monitoring techniques for computer-integrated manufacturing.

2. Data acquisition design and OES modeling scheme

2.1. Characteristics analysis and modeling of conventional OES

For the plasma process, the measurable incident angle of optical fiber should be characterized. Based on this characteristic of optical fiber, it is available to classify measurable and un-measurable region in the plasma process chamber. To analyze the characteristics of conventional incident-angle-dependent OES, a grid with regular interval and angle is indicated, as shown in Fig. 2. After placing the optical fiber for OES at the origin of this grid, the light source is moved along the indicated path, and the light intensity is measured using OES. The result is shown in Fig. 3. In Fig. 3, the positional light intensities are different according to the distance and radius. This experiment shows that the measurable incident angle is approximately 30°–40°.

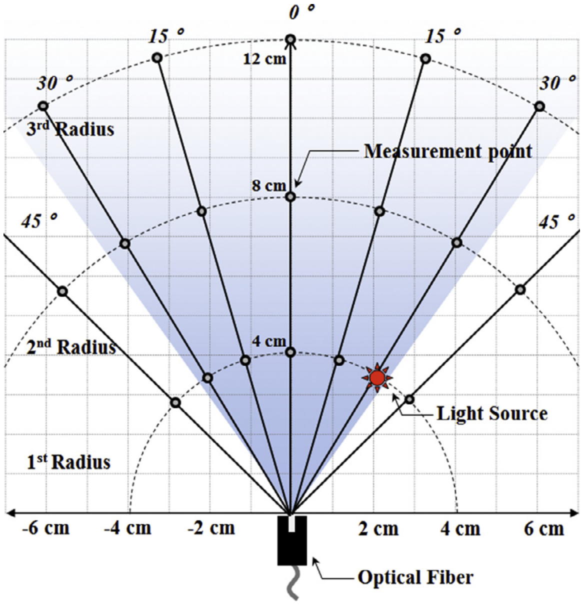

Fig. 2. Experimental setup for determining characteristics of incident-angle-dependent OES.

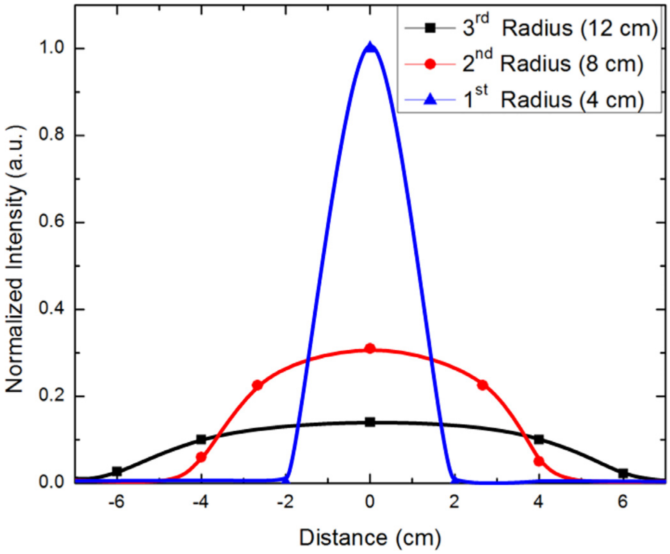

Fig. 3. Positional light intensity by incident angle according to distance and radius.

Although conventional OES is able to acquire light at incident angles of 30°–40°, other areas cannot be measured. For 200 mm or 300 mm tools, OES can measure only less than 50% of the total area, as shown in Fig. 1. The measurable area is calculated as follows:

After defining grids for 200 mm or 300 mm tools using computer software, the number of blocks under the specific incident angle can be calculated. The results from the angle calculation are summarized in Table 1. As the angle increases, the measurable area also increases. The incident angle of conventional OES produces an ambiguous region in the plasma process chamber. Due to this, the measuring capability of conventional OES, such as for micro arcing and plasma abnormalities, is relatively poor. Thus, in this paper, the characteristics of OES measurement for both narrow and wide incident angles are investigated.