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A micro-view-based data mining approach to diagnose the aging status of heating coils

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A B S T R A C T

The aging status of heating coils dramatically influences the semiconductor process with respect to the operating fluency and the cost of non-warning breakdowns. Diagnosing the health status of heating coils is a critical issue in the manufacturing industry, but very few studies have dedicated their efforts to discovering relevant remedies. This study proposes a novel observation perspective that grasps the micro view of data information from real processes, and does not lose its effectiveness even if the recipes vary. The proposed aging measuring includes the following main procedures: firstly, acquiring specific process flows composed of recipe steps; secondly, analyzing the local areas corresponding to each process flow; thirdly, capturing sensing values and the corresponding setting information related to the specific process flows; fourth, generating a local feature in a time interval corresponding to each of the process flows according to the corresponding local areas; finally, generating an aging trend on the basis of the local features, and determining whether to send a replacement early-warning. The experiments show that the proposed approach to the aging diagnosis can effectively offer a replacement warning before the heating coils run down.

1. Introduction

The machines used in the semiconductor field possess high stability and huge price, but they break down without warning caused by aging leading to process stagnation and added cost [1–3]. In particular, the heating system consists of several expensive components which cost tens of thousands of dollars and, as the heating process influences the manufacturing procedure throughout, providing early warning for replacement of aging parts is an urgent requirement [4,5].

Fault detection of aging components or products can be roughly divided into two categories. One is like a keyboard, watch or car; since the sample can be obtained from many users, the aging estimation is not so difficult. The other is like the component parts in semiconductor manufacturing, which entails high stability and few damaged samples, so it is tough to construct a robust approach to the estimation of aging.

Currently the heater used in semiconductors on the market comprises electric coils and conductive films; also, the heating modes encompass tungsten coils' infrared radiation and iron sheets' thermal conductivity. However, the heating effectiveness of tungsten coils has the advantages of fast, uniform heating, and easy replacement, so most of the semiconductor manufacturing today adopts tungsten coils [6,7]. In this study, we estimate the aging state of the heating coils and propose a method to advise the replacement timing based on the aging-related deterioration.

Traditionally, the diagnosis of the aging heating coils commonly employs the power signals, like the current or voltage [8,9]; however, the fault assessment often needs specific domain knowledge for a certain manufacturing recipe. In addition, such an approach is highly dependent on experts in the field in order to interpret the special data related to the power signals.

On the other hand, for the sensing values, a corresponding "standard value" is essential to serve as a basis of fault assessment. Nevertheless, the predetermined "standard value" cannot always be directly applied to the fault assessment in other processes with different or new recipes. In such cases, the interpretation of the data or realization of the fault degree is highly dependent on experienced engineers or multi-year experimental rules.

In the aging assessment of heater coils, the dataset is retrieved from real sensing values, including temperature, power, wafer curvature, and reflectance from the laser. The data used in this study are employed in two novel directions. One is the setting values, which can help the user observe the difference between sensing and setting values. When the machine is more stable, the gradual

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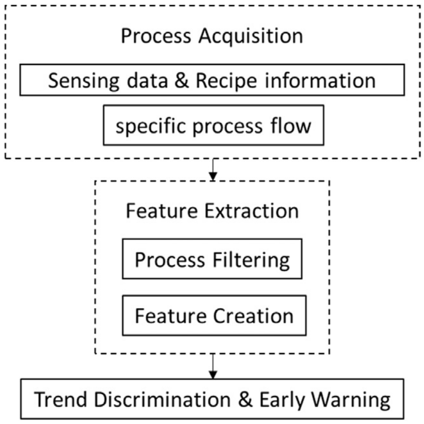

Fig. 1. Executing flowchart.

changes from the slight differences between sensing and setting values become more representative of the aging status.

Another direction is feature extraction from the micro-viewpoint. In the conventional practice, it is intuitive to get features from the entire manufacturing process; i.e. the unit of extracting a feature is based on a particular period of processes such as an hour, a workday, etc. This study adopts a novel idea, extracting "local features" which are hidden in the difference between the setting and sensing values. Importantly, as the proposed local features are attributed to the stable physical properties, the particular feature values can be effectively embodied in some local differences (explained later in detail).

Moreover, the features obtained from the above two directions will not be limited by different recipes, i.e. recipe-independent features are proposed. The feature extraction process will be explained in more detail in the following sections.

The proposed approach to aging diagnosis includes the following steps. The first step is to retrieve numerous process flows; each process flow contains at least one recipe step. Then, we analyze the process flow to determine what process property corresponds to each flow. Third, according to the process property, the local features can be generated in the corresponding time interval. Finally, we construct an aging trend based on local features and determine whether an early warning should be issued.

The remainder of this paper is organized as follows: Section 2 details the proposed methods regarding how to retrieve the local features from the process details. Section 3 illustrates the experimental results in the real dataset. Conclusions are finally drawn in Section 4, along with recommendations for future research.

2. Methodology

In this section, we introduce the proposed aging-related diagnosis of heating coils. Fig. 1 is the executing flowchart, including process acquisition, feature extraction, trend discrimination and early warning. The following subsections detail the technologies.

2.1. Process acquisition

The process acquisition involves data preprocessing, and can be viewed as a two-stage process. The first stage is using file-read-in or database access to the sensing data and recipe information. Another step is to capture a specific process flow, including the heating and constant temperature, which are both in power-on situations.

For the first stage of process acquisition, the data used in this study are retrieved from the industry, and the process is recorded in ERP and collected in log files. Apart from the sensing data and recipe information, the maintenance and replacement timings are also adopted.

The second stage is essential in the acquisition process as detailed in the following description. The purpose of process acquisition is to capture the process flows; each process flow comprises at least one recipe step. In this study, the recipe step corresponding to the heater operation can be categorized into three types: a heating procedure, which means a temperature rising stage; a smooth procedure, which means a thermal preservation stage, i.e. a constant temperature situation; a hybrid of two process flows: the temperature rises in a smooth procedure.

We note that the cooling flow is not considered here because the cooling procedure occurs when the heater is powered off and thus the temperature falls. In other words, the cooling procedure does not belong to an operating situation; thus, any process flow related to a cooling process does not need to be considered in the process acquisition. Fig. 2 shows a partial process under a certain working unit. Such a partial process is called a *run* in this study, and is usually known as a data unit like a workday.

The vertical and the horizontal axes represent the heating temperature and execution time, respectively. The thick black line indicates the temperature measured by the sensor, and the dotted line is the corresponding recipe setting. It can be directly observed that the sensing value and the recipe setting are very close to each other. It is also intuitively reasonable that the sensing value is supposed to follow the recipe setting in order to ensure a good yield.

However, due to the natural physical properties, the sensing values are relatively "passive" compared to the recipe settings. Such passivation acts just like the centrifugal force in nature or a gradual relaxation of braking systems; these are irresistible natural phenomena arising from the difference between the sensing value and recipe setting, which is exactly the core idea for extracting the local features. Importantly, the difference is believed to increase during the utilization of the heating coils. It is of special significance that such local features are not affected by the recipe settings since any heating recipe setting is made up of the three flows: heating, constant temperature, and cooling-down.

The difference mentioned above must be a specific process flow, and needs to be observed by enlarging the detail. Specifically, for the heating portions, the recipe settings and the sensing values possess a nearly parallel gap, which is expected to gradually broaden when the coils are kept working; besides, the portions rising to the constant temperature show that the sensing values possess a circuitous area with instability. The above-mentioned nearly parallel gap and the circuitous area with instability will be detailed later as the critical characteristics of feature extraction.

2.2. Feature extraction

In Section 2.1, after the specific process flows are identified, they must also be filtered according to the temperature range. For example, the data attribution in rising to 800°C and 1400°C essentially signifies different heating properties, so temperature should be a filtering criterion for facilitating the subsequent analysis under different data levels. After the filtering step, we may generate some features to identify the aging trend for specific process flows within a filtered temperature range. Thus, this section will describe two issues: process filtering and feature creation.

2.2.1. Process filtering

Fig. 3 is a processing run, it shows that the whole process can be divided according to three types of temperature settings: heating, constant temperature and cool-down, and each color represents a specific temperature setting. But even if the temperature

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