Journal of Aerosol Science 88 (2015) 148–158

Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

Investigation of particulate contamination of heated wafers contained in a closed environment

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ARTICLE INFO

Article history:
Received 14 February 2015
Received in revised form
13 June 2015
Accepted 25 June 2015
Available online 4 July 2015

Keywords:
Closed environment
FOUP
Wafer
Particulate contamination
Natural convection

ABSTRACT

In this study, the phenomenon of particulate contamination of heated wafers contained in a closed environment like the front opening unified pod (FOUP), which is a fundamental component of minienvironment system in semiconductor manufacturing, was elucidated both experimentally and numerically. The degree of particulate contamination of heated wafers was examined according to the position of the wafers in the closed environment. The results showed that particles, if any, generated inside the closed environment such as the FOUP could be carried by natural convection flow and deposit on the heated wafer placed at the upper position in the closed environment. As a result, the topmost wafer was the most vulnerable to particulate contamination. The effect of the wafer temperature on the degree of particulate contamination of the topmost wafer was investigated, and a narrower contaminated area appeared at a higher wafer temperature condition.

1. Introduction

With increasing pattern density in semiconductor manufacturing technology, the wafer size has been increased to 450 mm and the pattern width has been reduced to 10 nm. Owing to the decrease in pattern width, the minimum size of killer particles continuously shrinks, resulting in additional cost or a treatment for controlling particulate contamination. Therefore, it is of great importance to reduce the level of particulate contamination, and a lot of efforts have been done to lower particle concentration by investigating the airflow in cleanrooms including minienvironments. Particle concentration could be reduced as a result of the improvement of airflow velocity distribution by reducing the airflow rate of exhaust fans and installing additional fan filter units (FFUs) (Noh, Kim, & Oh, 2010). The particle concentration in a cleanroom was greatly influenced by the air change rate and free area ratio of raised-floor (Khoo, Lee, & Hu, 2012). The particle contamination to a coating process could be reduced by using a minienvironment, and the reduction in particle concentration was affected by the operating conditions of the door and exhaust of the minienvironment (Chuah, Tsai, & Hu, 2000). A minienvironment was designed to have a buffer zone between the ambient and the process zones, and the buffer zone could effectively protect the process zone from particulate contamination (Hu, Chuah, & Yen, 2002).

For effective control of particulate contamination, it is of great importance not only to reduce particle concentration by adjusting airflow in cleanrooms, but also to understand the rate of particle deposition onto wafers at given conditions of the particle concentration and airflow distribution. In general, the air supplied from FFUs installed in the ceiling flows vertically

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http://dx.doi.org/10.1016/j.jaerosci.2015.06.005
0021-8502/

downward, and thus a lot of studies on particulate contamination of wafers or photomasks situated in vertical airflow have been conducted. The degree of particulate contamination of freestanding wafers or photomasks in vertical airflow was investigated with the consideration of diffusion and gravitational-settling of particles (Liu & Ahn, 1987; Otani, Emi, Kanaoka, & Kato, 1989; Pui, Ye, & Liu, 1990; Bae, Lee, & Park, 1994; Kim, Lee, Yook, & Lee, 2014). The influence of thermophoresis was taken into consideration to investigate the degree of particulate contamination of wafers in vertical airflow (Ye et al., 1991; Bae, Lee, & Park, 1995; Yoo & Oh, 2005; Yook et al., 2007a). The degree of contamination of wafers by charged particles in vertical airflow was examined under the combined effects of thermophoresis and electrophoresis (Opiolka, Schmidt, & Fissan, 1994). In semiconductor manufacturing processes, wafers and photomasks are generally exposed to vertical airflow, but they are also situated in horizontal airflow, e.g., when they are transported by robot arms. The degree of particulate contamination of wafers or photomasks in horizontal airflow was investigated by considering diffusion and gravitational-settling of particles (Yook & Ahn, 2009; Choi & Yook, 2010; Yook, Asbach & Ahn, 2010a; Yook, Hwang, Lee & Ahn, 2010b; Lee & Yook, 2011; Lee, Kim, & Yook, 2011). The effect of thermophoresis or electrophoresis on the degree of particulate contamination of wafers or photomasks exposed to horizontal airflow was examined (Kim, Lee, & Yook, 2011; Woo, Lee, & Yook, 2012a; Woo, Yook, & Han, 2012b; Kang, Yook, & Lee, 2014a; Lee, Yook, & Lee, 2014). Moreover, thermophoresis and electrophoresis were simultaneously taken into consideration to investigate the behavior of the degree of particulate contamination of wafers or photomasks in horizontal airflow (Lee, Yook, & Han, 2012a; Lee, Yook, & Han, 2012b; Lee & Yook, 2014; Kang, Yook, & Lee, 2014b).

The aforementioned studies mainly focused on particulate contamination in the open space of a cleanroom environment. During the semiconductor manufacturing process, however, wafers are generally stored in the front opening unified pod (FOUP), which is a good example of the closed environment, for transporting the wafers efficiently and enhancing the yield. The wafers spend most of their time in the FOUP, except when they undergo process in equipment. It is therefore important to evaluate the particulate contamination of wafers inside a closed environment as well as that in an open environment. Several studies on the particulate contamination of wafers contained in an FOUP have been conducted by investigating the effects of the door opening speed and wafer position (Kobayashi, Kobayashi, Tokunaga, Kato, & Minami, 2000; Hu & Hsiao, 2005; Hu, Ku, Shih, & Hsu, 2009). These studies, however, considered the inflow of air from a minienvironment into the FOUP due to the opening of the FOUP door. In other words, the particulate contamination of wafers stored in the FOUP with the door closed needs to be further investigated.

Because most semiconductor manufacturing processes are carried out in high-temperature conditions, hot wafers are likely to be stored in the FOUP for the purpose of reducing the time interval between processes. The high temperature of the wafers is anticipated to induce natural convection in the FOUP, and particles generated by friction during transportation or movement of the FOUP can flow owing to this natural convection inside the FOUP and may deposit on the wafer surface. However, to the best of the authors' knowledge, there have been no studies on particulate contamination of the wafers stored in an FOUP, that is, in a closed environment. The objectives of this study, therefore, are to elucidate how particles contribute to contamination of heated wafers stored in a closed environment and to specify the locations of critical contamination spots on the wafer surface.

2. Experimental

Experiments were performed using fluorescent particles to visibly verify the level of particulate contamination of wafers stored in a closed environment. A plastic chamber (250 mm × 250 mm × 200 mm) made of polycarbonate, having a thermal conductivity of 0.19 W/(m K), a density of 1210 kg/m^3, and a specific heat of 1130 J/(kg K), was used to mimic an FOUP. As

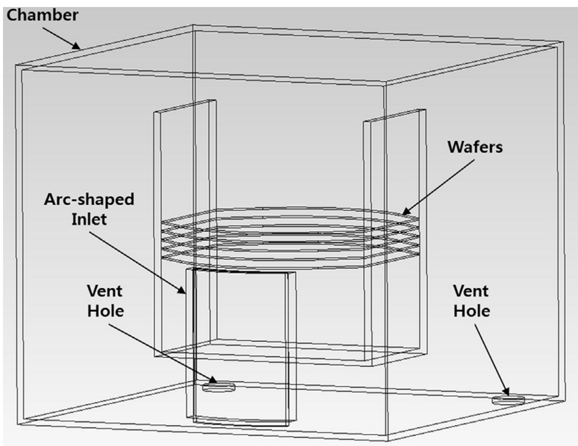

Fig. 1. Schematic of the FOUP-mimicking chamber containing five wafers.