行政院國家科學委員會專題研究計畫成果報告

計畫編號：NSC 90-2320-B-002-179
執行期限：90 年 8 月 1 日至 91 年 7 月 31 日
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一、中文摘要

本研究之目的在於調查晶圓廠機台維修人員可能砷暴露情形，並推估其潛在砷暴露作業下可能發生的健康風險值。研究結果發現，維修保養工程師之尿中總無機砷代謝產物平均為 32.8±29.1μg/L，而對照組則為 32.1±25.1μg/L。但比較三名維修工程師在同一日工作前與下工後的尿中總無機胂濃度的結果顯示，本研究維修工作區有明顯的職業性砷暴露。同時，而在維修工程師之終生癌症風險的推估方面，以蒙地卡羅模擬的結果，工作五年的平均終身癌症風險值為 3.58×10^{-5}，接近一般認同之可接受的風險值 10^{-4}～10^{-6}。此外，針對有無配戴個人防護具來進行維修作業的模擬分析結果顯示，沒有配戴個人防護具的情況下會有五倍高的終身致癌風險值。同時在此模擬模式的敏感度分析結果顯示，敏感度最高的參數依次是尿中砷濃度值、暴露頻率，以及體重。

關鍵詞：半導體業、尿中砷濃度、風險推估、蒙地卡羅模擬

Abstract

The aims of this study is to investigate the possible arsenic exposure among the maintenance engineers of wafer fabrication facilities, in order to predict the potential health risk after long-term occupational exposure to arsenic. For urinary arsenic level, average urinary arsenic levels of control group and maintenance engineers were 32.1±25.7μg/L and 32.8±29.1μg/L, respectively. However, by comparing the urine arsenic concentrations before and after workshift of three preventative maintenance engineers, occupationally exposure to arsenic is strongly suggested in the study site. Meanwhile, the average of Incremental Lifetime Cancer Risk of the maintenance engineers for working 5 years was 3.58×10^{-5}, within the universally acceptable level of 10^{-6}~10^{-4}. Besides, the simulation results of life cancer risk for those engineers not wearing personal protective equipment at work were nearly five times the risk for these wearing. The sensitivity analysis indicated that the input variables which are more sensitive in the risk estimation for preventative maintenance engineers exposure to arsenic are concentration of urinary arsenic, exposure frequency, and body weight.

Keywords: semiconductor, urinary arsenic, risk estimation, Monte Carlo simulation.

二、緣由與目的

The semiconductor industry has been an enormous worldwide growth industry. At the heart of computer and other electronic technological advances, the environment in and around these manufacturing facilities has not been scrutinized to fully detail the health effects to the workers and the community from such exposures. Hazard identification in this industry leads to the conclusion that there are many sources of potential exposure to chemicals including arsenic, solvents, photoactive polymers and other materials. Among them, inorganic arsenic is frequently used as a dopant material in diffusion furnaces and ion implanter. During these process, arsenic-containing byproducts, such as arsenic trioxide, are deposited on surfaces inside the reaction chamber. These byproducts can generate arsenic-containing particles, which creates the potential for exposure to workers when maintenance is performed on the reactor. Chronic exposure to inorganic arsenic is known to cause lung, skin, and a variety of other cancers.[1, 2]

The purpose of this study was to evaluate the risk exposure to arsenic of these maintenance workers in semiconductor manufacturing. It was also attempted to illustrate the relationship between inorganic arsenic metabolites of these personnel and the arsenic levels of their working environment.

The present study is therefore proposed to investigate the possible arsenic exposure among the maintenance engineers of wafer fabrication facilities, in order to predict the potential health risk after long-term occupational exposure to arsenic. Based on the urinary arsenic distribution of study subjects and the percentage range of the absorbed arsenic excreted through urine, the daily arsenic intake can be estimated by applying Monte Carlo Simulation.

三、研究方法

Part I of this study is field survey in a wafer fabrication company, involving arsenic exposure in the work environments of two ion implanters and seven diffusion furnaces of a wafer fabrication company, which use elemental arsenic and/or arsine gas as the raw materials for implantation or dopant in the manufacturing process. Air samples, wipe samples, urine samples, and hair samples were collected for arsenic and/or arsine exposure monitoring. These samples were analyzed with hydride generation atomic absorption spectrometry except arsine in air samples, which was analyzed with graphite furnace atomic absorption spectrometry. Besides, personal information about the subjects were collected via questionnaire administration.

Part II: Estimation of potential cancer risks

This part of study was to comprehensively investigate the possible arsenic exposure among the maintenance engineers of wafer fabrication facilities for S-RAM and D-RAM, and to predict the potential health risk after long-term occupational exposure to arsenic. Data of a previous study conducted in 2000 by the same research team and the survey of the present study aforementioned were combined in the risk estimate. In the combined dataset, Group A consisted of 30 engineers for ion implanter maintenance and 12 office industrial hygienists as control group. And, Group B, i.e. the present survey, was comprised of 51 engineers for ion implanter and diffusion furnace maintenance and 10 engineers of Environmental Safety and Health department who worked in the office and served as control group.

The methodology for estimation of cancer risk from the USEPA was applied in the present study. For carcinogenic effects of inorganic arsenic, risk is expressed as excess probability of contracting cancer over a lifetime (70 years).[3,4]

四、結果與討論

All maintenance engineers were male with an average age of 28.4±3.2 years old, compared to 29.5±2.9 years old of the non-exposed group. Average urinary arsenic level of control group was 32.1±25.7μg/L, while that for maintenance engineers was 32.8±29.1. No significant difference between the preventive maintenance engineers and controls, average around 0.03 μg/g.

Airborne arsenic samples were only found in some sampling sites from the diffusion furnace of Type A machine, i.e., from 0.01 to 0.16 μg/m^3, and some ion implanter area, ranging from 0.09 to 37.0 μg/m^3. Overall, such results revealed that only parts of the maintenance activities might produce high level arsenic exposure. All of the 45 area samples were detectable for arsine, varying from 0.06 to 2.19 ppb, well below the occupational exposure limit of 50 ppb. On the other hand, dust arsenic loading on workplace surfaces (wipe samples) varied from non-detectable level to 1237 ng/cm^2.

In the present study, it is found that, for some subjects, their urinary arsenic concentrations in one week might vary from around 20 μg/L to 70~80 μg/L, sometimes even greater than 100 μg/L. Since the control group did not work with the arsenic-related operation during the survey period, the increase and decrease of their urinary arsenic concentration should be attributed to other reasons, such as specific diet, or other arsenic exposure. Nevertheless, for the control group, the lowest urinary arsenic level of each subject, mostly ranged from 15~30 μg/L, can be used for baseline reference of urinary arsenic concentration without any special arsenic exposure other than background.

However, for comparison of circadian change of urinary arsenic level, this study has collected two urine samples, before and after work shift of the same day, from each of three maintenance engineers of furnace group for arsenic determination. The results showed that, the urinary arsenic concentrations of three urine samples collected before work shift in the morning were all lower than those of the after-work urine samples. They were 35.8ug/L vs. 58.3ug/L, 34.4ug/L vs. 59.4ug/L, and 64.7ug/L vs. 101.4ug/L, respectively. Such elevation of urinary arsenic level in a day strongly suggested the direct and/or indirect occupational arsenic exposure during the maintenance operation.

Crystal Ball was chosen for Monte Carlo simulation in the present study, and run in conjunction with Excel on Microsoft Windows system [5] with 10,000 iterations for each simulation. We estimate the probability density functions (PDFs), cumulative distributions functions (CDFs), and summary statistics for the Lifetime Cancer Risk (LCR) based on exposure duration of 5 years, 10 years, 20 years, and 30 years (Table 1). Generally speaking, the Incremental Lifetime Cancer Risk of the maintenance engineers for working 5 years was within the range of universally acceptable level in 10^{-6}~10^{-4}.

We also estimated the potential life cancer risk by the assuming the preventative maintenance engineers without wearing respiratory protect during preventive maintenance. It was supposed that the engineers who did not wear respiratory protect may result in the rise of fraction in airborne arsenic of inhalation up to 50%. The simulation results of life cancer risk were nearly five times the risk of wearing respiratory protect.

For the exposure risk assessment, sensitivity is defined as the ratio of the relative change in the output (e.g., Lifetime Cancer Risk) produced by a unit relative change in the variables, e.g., fraction of airborne arsenic inhaled. The present study indicated that the input variables which are the most sensitive in risk estimation of preventative maintenance engineers exposure to arsenic are: concentration of urine arsenic (UAs), exposure frequency (EF), and body weight (BW). In this study, the distributions for these variables were based on empirical data, suggesting a fairly high confidence level in the results of our probabilistic analysis.

It is recommended to keep monitoring on the trend of urinary arsenic concentration regularly in order to find out the potential arsenic exposure risk during operation. For further analysis on arsenic exposure at work, it is suggested to make comparison of urinary arsenic concentrations before and after work of the same day to elucidate the association of potential exposure dosage and work content. And, since arsenic exposure source in other than fab environment might have influence on the variation of urinary arsenic concentration in this study, it is necessary to figure out the effect of other possible arsenic exposure sources, for example, residual arsenic dust coming from fab maintenance work, or possible arsenic contamination in food.

五、參考文獻

1. World Health Organization. IARC monographs on the evaluation of the carcinogenic risk of chemical to humans：Some metal and metallic compounds. Lyon, International Agency for Research on Cancer, 1980.
2. International Agency for Research on Cancer. Evaluation of carcinogenic risks to humans, Lyon, International Agency for Research on Cancer 1987; Supplement 7: 100-106.
3. USEPA. Risk Assessment Guidance for Superfund (RAGS), Vol.1, Human Health Evaluation Manual, part D, 1998. Available:

http://www.epa.gov/superfund/programs/risk/ragsd/index.htm.
4. USEPA. Guidance for Risk Characterization. U.S. Environmental Protection Agency, Science Policy Council, 1995. Available: http://www.wpa.gov/ORD/spc/rcguded.htm.
5. Decisioneering Inc. Crystal Ball 2000 User Manual. Denver, Colorado: USA Decisioneering Inc, 2000.

Table 1. Potential cancer risk with various working duration based on Monte Carlo Simulation.*

Exposure Duration	Mean	50 %	95 %	Min	Max
5 years	3.58×10^{-5}	2.92×10^{-5}	8.41×10^{-5}	2.10×10^{-6}	2.70×10^{-4}
10 years	7.25×10^{-5}	5.91×10^{-5}	1.67×10^{-4}	4.97×10^{-6}	7.52×10^{-4}
20 years	1.43×10^{-4}	1.17×10^{-4}	3.34×10^{-4}	1.08×10^{-5}	1.25×10^{-3}
30 years	2.17×10^{-4}	1.79×10^{-4}	4.96×10^{-4}	1.67×10^{-5}	1.86×10^{-3}

* Run with 10000 iterations.