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Biological monitoring of arsenic in semiconductor workers

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In the manufacture of integrated circuits involving semiconductors, various hazardous materials including arsenic compounds are used. This paper presents an evaluation of the biological monitoring of arsenic in the urine, blood and hair of semiconductor workers. Eighty-two blood samples were obtained from research and development workers in a semiconductor factory. Thirty-one samples of urine were obtained from the same group of workers before and after a work period (one shift). Seventy-three hair samples were similarly obtained from the workers. The concentration of arsenic in each sample was determined by arsine (AsH_3) generation flame atomic absorption spectrometry after wet ashing of the sample. The mean concentration of arsenic in hair in these semiconductor workers was significantly higher than that of controls. The mean concentration of arsenic in hair from workers with a longer employment duration was higher than from those with a shorter employment duration. The mean concentration of arsenic in hair from workers engaged in epitaxial growth processes was higher than from workers engaged in other processes. The concentrations of arsenic in hair from semiconductor workers correlated with the duration of their employment. The mean concentration of arsenic in urine before a work period (shift) was not significantly different from that of controls. The mean concentration of arsenic in urine after a work period was in fact lower than that of controls. The mean concentration of arsenic in blood was not significantly different from that of controls. The determination of arsenic in hair is therefore considered useful for the evaluation of relatively long-term exposure to arsenic in semiconductor workers.

Keywords: Arsenic, biological monitoring, semiconductor manufacture, hair analysis

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INTRODUCTION

Many chemicals are used in semiconductor manufacturing during the production of integrated circuits (IC). Laboratory workers engaged in research and development have an increased liability to exposure to chemicals, though this exposure is not constant.

Because IC processes are usually operated under clean room conditions, space and exposure monitoring using pumps are more difficult to undertake. Therefore, biological monitoring of arsenic is preferable for the evaluation of exposure to arsenic compounds in semiconductor workers.

In this study, biological monitoring of arsenic in semiconductor workers using urine, blood and hair was undertaken and evaluated.

EXPERIMENTAL

Eighty-two blood samples were obtained from laboratory workers in a research and development semiconductor laboratory. Samples of urine were obtained from 31 workers in the same group before and after a working period. Dietary intake of fish, shellfish or seaweed (which may contain arsenic) had been restricted to zero on the day of sampling and on the day prior to sampling. Seventy-three hair samples were obtained from workers of the same group. The mean age and length of employment were 29.9 (range 18–52) and 5.0 (range 0.1–16) years respectively.

One hundred and thirty blood samples and one hundred and three urine samples were obtained as controls from workers not exposed to arsenic in their occupational environment. Their mean age was 18.4 (range 18–35). One hundred and four control hair samples were obtained from a barber remote from semiconductor workers. The mean age was 38.8 (range 5–65).

Samples of hair were washed with acetone to remove grease or oil. Blood, urine and hair were washed with

a mixture of nitric and sulfuric acids. The concentration of arsenic in each sample was determined by flame atomic absorption spectrometry that involved reduction of arsenic to its volatile hydride using stannous chloride and zinc.[2] The urinary concentrations of arsenic were adjusted to a specific gravity of 1.020.

RESULTS AND DISCUSSION

Mean concentrations of arsenic in the samples from semiconductor workers

The arithmetic mean concentration of arsenic in hair of semiconductor workers was significantly higher than that of the control group, as shown in Table 1 ($P<0.05$).

The mean concentration of arsenic in urine before working a shift was not significantly different from that of controls. The mean concentration of arsenic in urine after working was actually lower than that of controls. Although the chemical species of arsenic in urine were not determined in this study, the excreted arsenic in urine is considered to be derived from dietary organic arsenic compounds. Stricter restriction of dietary arsenic in the semiconductor workers studied (compared with the controls) probably contributed to their lower excretion of arsenic in urine after working.

The mean concentration of arsenic in blood was not significantly different from that of the control group.

The mean arsenic concentrations in hair and urine obtained from these semiconductor workers were lower than previously reported concentrations of arsenic in exposed workers and controls.[1] Therefore, the exposure level of arsenic of the workers in this study is considered to be fairly low.

Duration of employment and concentrations of arsenic in the samples

Table 2 shows the mean arsenic concentrations in groups of workers with various durations of employment. There was a tendency of the arsenic concentration in the blood to be higher the longer the workers had been handling arsenic compounds. The arithmetic mean concentration of arsenic in the blood of workers having been exposed to arsenic for three or more years was 0.7547 g per 100 g, which was significantly higher than that of workers exposed for less than three years ($P<0.05$).

A stepwise increase with duration of employment of the mean concentrations of arsenic in the hair of workers was also observed. This finding was observed in the previous report.[1] The arithmetic mean concentration of arsenic in the hair of workers having worked six or more years was significantly higher than that of controls ($P<0.05$) as well as that of workers having worked less than six years ($P<0.05$).

The analysis of chemical species of arsenic in hair suggested that arsenic in hair is mainly inorganic with traces of dimethylarsinic acid and was derived from contamination.[1] However, higher arsenic concentrations in the hair of workers with longer durations of exposure may suggest that part of the arsenic content of hair reflects a body burden of arsenic derived from working with arsenic compounds.

Correlation matrix of concentrations of arsenic in samples and duration of work

A correlation matrix of concentrations of arsenic in urine, blood, hair and duration of work is shown in Table 3. A high correlation coefficient was obtained

Table 1 Mean arsenic concentrations in urine, blood and hair of semiconductor workers

		Control			Semiconductor workers			
Specimen		*N*	Mean	*SD*	*N*	Mean	*SD*	*T*-test
Urine before work (one shift), $\mu g\ dm^{-3}$	A	103	75.090	31.425	31	85.722	120.89	n.s.
	G		69.552	1.461		58.755	2.1785	n.s.
Urine after work (one shift), $\mu g\ dm^{-3}$	A	103	75.090	31.425	31	65.183	78.329	n.s.
	G		69.552	1.461		45.728	2.2802	$P<0.01$
Blood, μg per 100g	A	130	0.7132[a]	0.8949	82	0.6217[a]	0.6927	n.s.
	G		0.5952	2.4914		0.4681	2.3877	n.s.
Hair, $\mu g\ g^{-1}$	A	104	0.0721	0.0478	73	0.0979	0.0907	$P<0.05$
	G		0.0657	2.1150		0.0790	2.3362	n.s.

Abbreviations: A, arithmetic mean and standard deviation; G, geometric mean and standard deviation; n.s., not significant.

[a] Blood was obtained at annual medical screening; hence there may be no consistent relationship between working time and the time of drawing blood.

Table 2 Mean arsenic concentrations in urine, blood and hair from three groups of workers with different durations of exposure

Specimen		<3 years			3–5 years			>6 years		
		N	Mean	*SD*	*N*	Mean	*SD*	*N*	Mean	*SD*
Urine before work (one shift), $\mu g\ dm^{-3}$	A	14	57.774	41.548	12	122.86	186.95	5	74.851[a]	29.371
	G	14	46.447	2.0086	12	71.593	2.5800	5	70.617[a]	1.4590
Urine after work (one shift), $\mu g\ dm^{-3}$	A	14	45.590***	22.147	12	91.903	120.71	5	55.917[a]	27.535
	G	14	39.487***	1.8605	12	52.110	3.0533	5	50.402[a]	1.6941
Blood, μg per 100g	A	34	0.4340**	0.3859	25	0.6752	0.6008	23	0.8410	1.0205
	G	31	0.3343**	2.5505	23	0.5853	1.9490	22	0.5952	2.3142
Hair, $\mu g\ g^{-1}$	A	28	0.0703	0.0488	24	0.0856	0.0488	21	0.1486*	0.1301
	G	23	0.0658	2.1881	23	0.0760	1.8568	21	0.1005	2.9630

Abbreviations: as in Table 1.

*** $P<0.001$; ** $P<0.01$; * $P<0.05$, compared with means of controls.

[a] May not be statistically significant in view of small control size of >6 compared with 3–5-year group.

between concentrations of arsenic in urine before working a shift and those after working ($r=0.967$ with measured value, i.e. calculated from logarithmically untransformed data). A moderate correlation coefficient was obtained between concentration of arsenic in hair and duration of exposure ($r=0.319$ with measured value). This relationship between the concentration of arsenic in hair and the duration of exposure was consistent with the results comparing the mean concentrations of arsenic in the hair of groups with different durations of exposure (Table 2).

Workplace and concentration of arsenic in samples

Forty-four workers were engaged in the epitaxial growth process, 29 in the ion implantation process, six in the fabrication of laser diodes and three in other processes. The mean concentrations of arsenic in the blood and hair of workers working in three major workplaces are shown in Table 4.

Because 27 out of 31 workers offering urine samples were engaged in the epitaxial growth process, this groups was not subdivided by workplace.

The mean concentration of arsenic in blood was highest from workers in the ion implantation process, while the highest value of arsenic in hair was observed from workers in the epitaxial growth process. The mean arsenic concentration in the hair of workers engaged in the epitaxial growth process was higher than that of controls ($P<0.05$). The mean arsenic concentrations in the blood of workers engaged in the epitaxial growth process ($P<0.05$) and laser diode fabrication process ($P<0.001$ for arithmetic mean,

Table 3 Correlation matrix of arsenic concentrations in urine, blood and hair, and duration of exposure

Factor		Urine		Blood	Hair
		Before	After		
Urine after work (one shift)	r[a]	0.967***			
		0.791***			
	N	31			
Blood	r[a]	0.355	0.265		
		0.167	0.212		
	N	29	31		
Hair	r[a]	0.103	0.008	0.135	
		0.155	0.022	0.036	
	N	26	28	69	
Duration of employment	r[a]	0.131	0.118	0.246*	0.319*
		0.254	0.138	0.263*	0.202
	N	31	31	82	73

*** $P<0.001$; ** $P<0.01$; * $P<0.05$.

[a] Upper row, measured value; lower row, value logarithmically transformed.

Table 4 Mean arsenic concentrations in blood and hair from three groups of workers working in different workplaces

Specimen		N	Arithmetic		Geometric	
			Mean	SD	Mean	SD
Blood, μg per 100g	E	44	0.4585	0.2951	0.3976*	1.9572
	I	29	0.9211	0.9949	0.6476	2.7850
	L	6	0.2214***	0.2017	0.2191*	0.9689
Hair, $\mu g\ g^{-1}$	E	40	0.1107*	0.1072	0.0782	2.3780
	I	26	0.0828	0.0651	0.0754	2.4594
	L	5	0.0846	0.0602	0.0978	1.6214

Abbreviations: E, epitaxial growth process; I, ion implantation process; L, laser diode fabrication process.
*** $P<0.001$; * $P<0.05$, compared with means of controls.

$P<0.05$ for geometric mean) were lower than those of controls.

Because of the fast decline of blood arsenic level after cessation of exposure,[3,4] arsenic level in blood is considered less useful than in hair for an evaluation of occupational exposure of arsenic. Therefore, these results imply that more cautious hygienic management should be given for the workers engaged in the epitaxial growth process.

Ungers and Jones[5] reported workplace monitoring, suggesting that ion implantation operators routinely were exposed to low-level concentrations of various dopants. However, the area and personal samples taken during normal operating activities found concentrations of arsenic, boron and phosphorus to be below OSHA (Occupational Safety and Health Administration) Permissible Exposure Limits for related compounds.

Because a previous report mentioned a high incidence of occupational illness for workers in semiconductor manufacturing,[6] care should be taken to assure the health and safety of microelectronics workers, particularly in the application of dopant gases.

CONCLUSION

The biological monitoring of arsenic in urine, blood and hair was evaluated in semiconductor workers. The exposure level of arsenic was thought to be very low in these subjects.

The mean concentration of arsenic in the hair of workers was higher than that of the controls. The longer the workers had been exposed to arsenic, the higher the mean concentrations of arsenic in hair and blood. The concentrations of arsenic in hair of workers moderately correlated with the duration of exposure.

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