RESEARCH ARTICLE

Occupational exposure to nanomaterials: Assessing the potential for cutaneous exposure to metal oxide nanoparticles in a semiconductor facility

This study evaluated the potential for cutaneous exposures to engineered nanometal oxides from workplace surfaces in a semiconductor research and development facility. Exposure assessment methodology captured engineered nanomaterials (ENMs) from work surfaces accessible for worker contact via the skin that were associated with chemical mechanical planarization (CMP), a polishing process utilized in semiconductor fabrication. A microvacuum approach was used to collect surface samples for morphological analysis via transmission electron microscopy (TEM) and scanning electron microscopy (SEM), both with energy-dispersive X-ray spectroscopy (EDS) for compositional analysis. Eleven surface samples were collected along the CMP lifecycle: 1 from the cleanroom ("fab") where wafer fabrication takes place, 4 from the subfab where bulk chemical delivery systems are located, and 6 from the wastewater treatment (WWT) area where CMP wastewater is treated and discharged. Engineered nanomaterials of interest (Si, Al, Ce) were found from all areas of collection, existing as particles or agglomerates (>100 nm). Results support the findings of prior research and indicate that nanomaterials utilized or generated by CMP are found on work surfaces and may be accessible for cutaneous exposure by workers in semiconductor facilities. In order to minimize and/or prevent cutaneous exposures for workers who use or handle ENMs in this industry, prudent preventive work practices should be followed, including use of personal protective equipment, hazard communication, and engineering and administrative controls.

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INTRODUCTION

Engineered nanomaterials (ENMs) are increasingly incorporated into a variety of manufacturing processes and consumer products spanning virtually every major industry, from health care and pharmaceuticals, to construction, energy, food, automotive, sports and recreation, and semiconductor. This has significantly affected the worldwide economy, with a $3.3 trillion impact on the global market for nano-enabled products by 2018.[1] At the same time, the nanotechnology workforce is rapidly growing, with an anticipated 2 million nanotechnology workers in the U.S. by 2020, with 6 million total workers in this field worldwide.[2] Risk assessment for the nanotechnology workforce is still in early stages since the toxicity of inhalation or cutaneous exposure to ENMs and the potential resulting adverse health effects are not well characterized or understood and occupational exposure assessment strategies have not yet been well established. ENMs may be more toxic than their bulk counterparts due to the unique physicochemical properties that emerge at the nanoscale. Surface area, size, and nanoparticle count are thought to be the most important factors in determining toxicity,[3,4] but other physicochemical parameters may also influence toxicity and may include morphology, surface characteristics, charge, functional groups, crystal structure, and solubility.[5,6] While assessment of the potential toxicity of nanoparticles is at an early stage, the development of occupational health and safety programs, including hazard surveillance and risk management is strongly recommended. Currently, numerous organizations including

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Table 1. Microvacuum Surface Samples Containing Materials of Interest Identified by EM.

			Imaging Modality		Materials of Interest			Samples Containing Si/Al/Ce			
Date of Capture	Sampling Location	Microvacuum Sample	TEM	SEM	Si	Al	Ce	<100 nm	100–500 nm	500–1,000 nm	>1,000 nm
2/5/2013	WWT	Hatch to acid filter tank	✓		✓	✓			✓	✓	✓
		Field blank	✓		✓	✓			✓		✓
2/6/2013	Subfab	Outside of door hatch to slurry dispenser A	✓		✓	✓			✓	✓	✓
		Outside of door hatch to slurry dispenser B	✓		✓	✓			✓	✓	
		Field blank	✓		✓	✓					✓
2/7/2013	Fab	Below door of CMP tool	✓		✓						✓
		Field blank	✓		✓	✓					✓
2/2013	N/A	Media blank	✓		✓	✓				✓	✓
10/8/2013	WWT	Hatch to acid filter tank[a]	✓	✓							
		Floor next to acid filter tank[a]	✓	✓	✓				✓	✓	✓
		Hatch to base filter tank[a]	✓	✓							
		Floor next to base filter tank[a]	✓	✓	✓	✓			✓	✓	✓
		Plastic wall covering next to sump pump valve[b]	✓	✓	✓	✓			✓	✓	✓
		Field blank	✓	✓							
10/25/2013	Subfab	Outside door to filter box to CMP tool 1	✓		✓	✓	✓		✓	✓	✓
		Outside door to filter box to CMP tool 2	✓		✓	✓				✓	✓
		Field blank	✓	✓							
10/2013	N/A	Media blank	✓	✓							
10/2013	N/A	Media blank	✓	✓							
TOTAL number of samples			19	9							
Number of samples containing material of interest/ total samples					13/19	11/19	1/19	0/19	8/19	9/19	12/19

[a] Materials of interest identified by SEM but not TEM; all others identified by TEM only.
[b] Materials of interest identified by both imaging modalities (TEM and SEM).