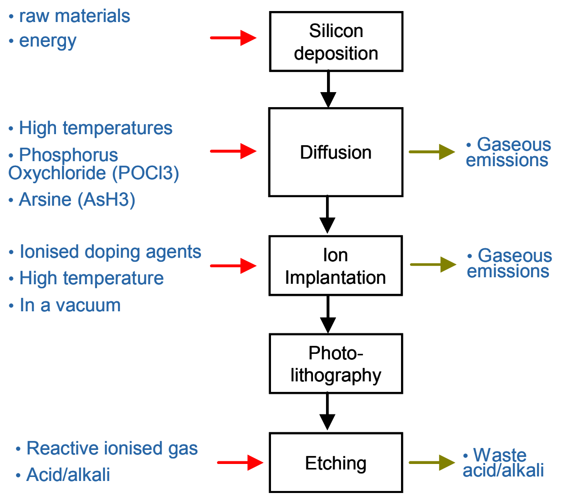
Sub-sectoral Environmental and Social Guidelines: Production of Semi-Conductors

European Bank for Reconstruction and Development

PROCESS DESCRIPTION

Over the last decade the semiconductor industry has been one of the world's fastest growing manufacturing sectors. The production of semi-conductors involves the fabrication of microelectronic circuits onto silicon wafers to produce electronic integrated circuit components. The manufacturing process consists of a varying number of stages. This guideline describes five key production steps and these are illustrated in the simplified process flow diagram below.



The main processes are:

1. **Deposition** of thin films onto the silicon wafer substrate. These layers may be built up by processes involving chemical vapour deposition, sputtering (electrical deposition of a metal onto the substrate under conditions of high vacuum) and oxidation. The raw materials for deposition are in the form of gases, solid metal and inorganic compounds;

2. **Diffusion** of doping agents into the wafer layer under high temperature conditions;

3. **Ion implantation** in which the silicon wafer is bombarded under high vacuum and temperature with a plasma of ionised doping agents;

4. **Photolithography**, during which a pattern or mask is superimposed onto a photochemically coated wafer; and

5. **Etching**, replicates the pattern from the mask to the underlying material. Both wet and dry etching methods are employed; wet etching uses a sequence of various chemicals (typically acidic), and dry etching involves wafers being processed in a chamber through which gases are pumped.

The entire manufacturing process takes place in cleanroom conditions, which require specific attention to air conditioning, protective clothing, etc..

Other activities undertaken on site are likely to include the packaging and dispatch of wafers, quality control and research and development. Limited machine maintenance may also occur.

KEY ENVIRONMENTAL, HEALTH AND SAFETY RISK/LIABILITY FACTORS

Water Usage & Wastewater

Water use in integrated circuit manufacture is among the highest of any industrial sector. The manufacturing process requires the provision of very large quantities of deionised water. Because of the purity required, recycling of process water is often not viable and wastewater discharge is therefore a significant issue.

Key regulations governing water usage and water quality include the EU Water Framework Directive and the US EPA Clean Water Act. As more countries experience water stress and water shortages the regulation of water will need to play an increasingly important role. This may be especially relevant to developing countries where water regulation has generally been less stringent and regular access to clean water may be limited.

Occupational Health and Safety Impacts

Many chemicals used in the production of semiconductors pose serious health risks including being known or suspected carcinogens. These chemicals include arsenic, arsine, benzene, cadmium, toluene, trichloroethylene and phosphine.

The handling of these harmful chemicals by employees is a major issue of concern and potential source of risk for a company.

Soil & Groundwater Contamination

Contamination of soil and groundwater as a result of losses from semiconductor manufacturing processes is common. This is no more apparent than in Silicon Valley, California which is home to no fewer than 29 toxic US "EPA Superfund" sites.

The most typical contaminants are chlorinated solvents and metals (particularly chromium, selenium and arsenic). Toxic solvents may also enter groundwater via leaking underground storage tanks. Each of these groups of materials can produce substantial impacts on the environment and human health.

The physical and chemical properties of chlorinated solvents make them of particular concern with respect to groundwater impacts. Remediation of chlorinated solvent plumes is often very expensive and slow.

Waste Management

- **Materials & Waste Storage -**The handling and storage of raw materials and liquid wastes presents significant challenges for the semiconductor manufacturing industry.

  Many of these materials, in particular solvents and gases, are in themselves very hazardous and highly mobile. Spillages and releases can occur at any time; however product delivery and waste removal operations represent particular hazards with respect to acute releases.

  Underground storage tanks and their associated supply pipework should generally be considered to be of suspect integrity. The flammable, toxic, reactive and volatile nature of some of the materials stored on semiconductor manufacturing sites presents additional difficulties for their storage and may make fire fighting hazardous.

- **Effluent Disposal** - One of the principal environmental issues associated with the production of semiconductors is the disposal of hazardous effluents.

  Typical constituents of effluents associated with integrated circuit board manufacture include deionised water, waste solvents, dissolved phase organic compounds, acids, photo resistant chemicals, dissolved metals (including arsenic, copper, chromium and selenium), waste etchants, waste aqueous developing materials and catalyst solutions.

Regulations such as the EU Water Framework Directive, the EU Hazardous Waste Directive and the Hazardous Waste Program of the US EPA's Resource Conservation and Recovery Act are among the leading global legislation in this area. These are only a part of a wider global regulatory trend geared towards reducing the volume of hazardous waste entering the natural environment.

This trend has already begun to spread to many developing countries and is expected to continue. Manufacturers of semiconductors may also find themselves being put under pressure by their customers in developed countries who may insist that their suppliers meet stringent EHS standards.

Solid Waste Management

Solid wastes generated during the manufacture of semiconductors are frequently hazardous and have a high potential for environmental impact. Typical solid wastes include metaliferous sludges, solder, air filters, gloves, scrap board metal, failed components and semiconductors.

OTHER ENVIRONMENTAL, HEALTH AND SAFETY RISK/LIABILITY ISSUES

Energy Usage and Carbon Emissions

As illustrated in the process flow diagram several stages of semiconductor production occur under conditions of high temperature. This together with the strict environmental conditions required and the mechanised nature of production means that semiconductor manufacturing processes tend to be energy intensive.

Despite this, the scope for energy efficiency gains is relatively modest given that most production facilities use modern equipment and that the ratio of energy usage for production purposes versus that used for general building supplies is very high.

Going hand in hand with the high energy intensity of semiconductor production are carbon emissions associated with energy generation. Such emissions may in future be regulated via emissions trading schemes such as the EU ETS, with potentially significant cost implications.

Ozone Depleting Substances

Semi-conductor manufacturing operations have traditionally been large users of ozone depleting chlorofluorocarbons (CFCs) both for manufacturing processes and for ancillary purposes such as refrigeration or fire control. Whilst these materials have been gradually phased out of the industry, the presence of residual volumes of CFCs in older cooling systems may be of concern.

Air Emissions

Typical constituents of emissions associated with integrated circuit board manufacture include acid fumes, volatile organic compounds (including methyl bromide), very hazardous gases (including arsine and phosphine), particulates and ammonia fumes. Point source emissions are likely to require air emission permits. Coating processes requiring the use of volatile organic solvents may also need permits.

Asbestos & Polychlorinated Biphenyls

Given the relatively recent development of the semiconductor industry, it is unlikely that the presence of either asbestos or polychlorinated biphenyls (PCBs) would present a significant issue for most semiconductor manufacturing facilities. In the rare instances where older buildings or services have been adopted by semiconductor manufacturers it may be appropriate to investigate the potential presence of these materials.

Raw Material/Supply Chain Issues

The global production of semiconductors requires significant amounts of raw materials that are obtained through mining. These mining activities have their own environmental, occupational health and community health and safety issues which are described in the EBRD Mining and Mineral Processing sub sector guidelines.

Noise

Air extraction fans and ductwork systems for fabrication units are usually large and may give rise to high ambient noise levels. The company's HSE Policy must specify the correct form of personal protective equipment that employees and visitors are required to wear.

KEY SOCIAL, LABOUR AND COMMUNITY RISK/LIABILITY ISSUES

Community Exposure to Contaminated Land and Water

If the activities taking place on the site result in the contamination of the area's land and water resources, this may have a negative impact on the health of members of the local community. This may expose the company to significant liability risk.

OTHER SOCIAL, LABOUR AND COMMUNITY RISK/LIABILITY ISSUES

End of Life Product Disposal and Recycling

The safe disposal of electronic waste (e-waste), much of which contains semiconductors, is an increasingly important issue in developing countries, including in Asia. Members of the community, often children, sort potentially toxic e-waste in order to recycle the valuable components. While providing a much needed source of income these activities also present substantial community health risks.

As a result more pressure is being placed on manufacturers to implement systems for the collection and safe disposal/recycling of their products.

Legislation such as the EU Waste Electrical and Electronic Equipment (WEEE) Directive and the Landfill Directive are among regulatory drivers increasing the visibility of end of life issues. Numerous countries around the world have either adopted or drafted legislation similar to the WEEE Directive and this trend looks set to continue.

Labour Standards

Labour standards are rules that govern working conditions and industrial relations. They may be formal, such as national level regulation and international agreements, or informal, expressed through norms and values. In general, developed countries have more robust labour standards than developing countries where the associated risks are higher. The commonly accepted rights and principles enshrined in the International Labour Organisation's standards are the right to collective bargaining, elimination of forced or compulsory labour, abolition of child labour and elimination of all forms of discrimination. In addition, fair wages and working hours and acceptable working conditions should be expected.

Acceptable labour standards should apply to the company's own employees as well as to all contractors and sub-contractors engaged. In addition, labour standards should be expected to be enforced by key suppliers.

Raw Materials/Supply Chain Issues

The global production of semiconductors and associated components requires significant amounts of polysilicon and other materials (e.g. metals) that are obtained through mining. The potential negative impacts of mining activities on local communities are described in the EBRD Mining and Mineral Processing sub sector guidelines.

FINANCIAL IMPLICATIONS

The principal aspects of financial risk associated with the environmental and social impacts of semiconductor manufacturing include:

Legal and Regulatory Impacts

- Contamination of land and water courses may result in both criminal and civil liabilities for the manufacturing company as well as substantial remediation costs;
- Any involvement in a mandatory carbon trading scheme will result in financial exposure for the company;
- Costs associated with the development and implementation of a product end of life collection, disposal and recycling scheme. These are relevant only in the case of vertically integrated semiconductor and electronic goods manufacturers.

Fines and Penalties

- Permits may be required for air emissions, hazardous materials storage and disposal, and wastewater discharge. Fines and penalties can be imposed as a result of a breech of permit requirements.

Capital Expenditure

- The costs of installing and maintaining wastewater treatment plants may be substantial.

Reputation

If the manufacturer's products or raw materials are associated with negative environmental or social impacts there is the risk that the reputational impacts will be reflected in consumer and even employee loyalty.

IMPROVEMENTS

Materials Storage

In relation to the semiconductor manufacturing industry, storage, containment and management of process materials and wastes, particularly fluids, is of critical importance for the protection of the environment. Where possible, all solvent storage and distribution systems should be placed above the ground surface and be subject to a programme of regular inspections and integrity testing. Gas storage should be segregated and secure, with specific provisions made for leak detection.

Water and Wastewater Management

Although large scale recycling of process water can be problematic because of the purity required by the manufacturing process, improvement of the overall management of water throughout the facility may provide substantial savings. The following actions should be encouraged:

- Where possible, recycling or reuse of water (e.g. grey water) either within the facility itself or by neighbouring consumers;
- Improvement of metering and control systems with the aim of minimising unnecessary losses; and
- Development or improvement of wastewater treatment infrastructure and quality monitoring programmes.
- Waste systems which may carry contaminated fluids should be constructed of materials which are resistant to the key contaminants.
- Where possible chemical sewer and contaminated water lines should be placed in channels which allow inspection of the lines and which provide secondary containment in the case of rupture of the line.

Groundwater treatment and protection

In areas where groundwater resources are considered to be sensitive, consideration should be given to the installation of groundwater monitoring wells and the implementation of a routine groundwater quality monitoring programme in the vicinity of the facility.

At a minimum, the programme should include analytical testing covering the main volatile organic compounds (VOCs) used in the facility, typical breakdown products of those VOCs and selected metals.

Should a Phase I Environmental Site Assessment (ESA) find evidence of potential contamination, a Phase II soil and groundwater investigation may be required. This investigation screens the soil and/or groundwater for potential significant contamination, or environmental liabilities and informs the remediation strategy by identifying the source(s) and extent of the contamination.

Atmospheric Emissions

Atmospheric emissions may be reduced through the installation of abatement equipment on all air emissions points such as gas reactor columns on all emissions from process areas and wet scrubbers on bulk acid storage tanks.

Energy Management

Although energy usage is a major issue in the semi-conductor industry, many of the processes required for their manufacture are inherently energy intensive and cannot yet be replaced with alternative technologies. In most instances, therefore, improvements to a facility's energy management will not result in great reductions in its overall energy use. Given the enormous consumption, however, worthwhile financial savings may be accrued through even a marginal percentage drop in energy requirements.

Dependent on the local characteristics there may also be potential for the on site generation of renewable energy (e.g. solar or wind) or the purchase of renewable power from energy generators. This will have a positive impact on the facility's carbon footprint and will mitigate some of the costs related to any future involvement in emissions trading schemes.

Waste Management

Waste streams should be segregated to minimise the volume of contaminated materials requiring treatment and to optimise recycling/reuse of materials.

Recycling

Solid waste generation tends to be low volume but high value. The recovery of precious metals from chips/boards is usually financially viable and will form an important driver of end of life disposal systems.

While this recovery is likely to be undertaken by dedicated waste processing operations, businesses in the semiconductor sector may have a role to play in designing products to encourage cost effective recovery of materials and in using recycled materials.

Recycling and/or reuse of process water should be promoted wherever possible within the water quality constraints of the facility.

Social, Labour and Community

Potential social, labour and community improvements may include:

- Implementation of a formal code of business conduct, which outlines the principles by which individual employees and the organisation must conduct themselves;
- Maintaining high labour standards and good quality working conditions.
- Paying fair wages in line with national law and sector standards average;
- Development of a policy covering labour practices for contractors and sub-contractors;
- Development of a whistleblowing policy to allow anonymous reporting of any ethical violations without fear of repercussion;
- Ensuring a fair and transparent tax contribution.
- Communicating with local communities to identify potential areas of concern and addressing the issues identified.
- In the event of trading difficulties, exploring all ways of limiting company redundancies.

GUIDE TO INITIAL DUE DILIGENCE SITE VISITS

Key issues which should be addressed during due diligence site visits are as follows:

Environment, Health and Safety

- Any history of or indications of contaminant impact on soil or groundwater in the vicinity of the site. Common indicators are ground staining and characteristic odours;
- The quality and sensitivity of groundwater in the area of the facility;

- The quality of provisions made for materials storage, particularly hazardous gas security and leak detection provisions and arrangements for the containment of liquid spills;
- The quality of provisions made for waste management. This should address the segregation of waste streams, labelling and provision of waste receptacles and the management of the waste transport and ultimate disposal;
- The adequacy of spill or emergency response equipment and procedures;
- The extent and condition of waste effluent systems;
- The control of "clean-room" areas;
- The presence of appropriate permits and licences for the operation;
- Site history with respect to compliance with permits and licences;
- Any history of enforcement notices or penalties imposed by regulators or service providers as a result of non compliance with licences or permits;
- Statutory or other land use restrictions (particularly for new plants);
- The presence of any sensitive neighbouring land uses (e.g. residential housing).

Social, Labour and Community

- Check that labour standards, contracting and remuneration are in line with national law and are consistent with the average for the sector;
- Check that hours worked, including overtime, are recorded and staff should receive written details of hours worked and payment received;
- Has the Company received inspections from the local labour inspectorate in the previous three years? Have these resulted in any penalties, fines, major recommendations or corrective action plans?
- Does the organisation have a grievance mechanism which allows employees to raise workplace concerns?
- Are employees free to form, or join, a worker's organisation of their choosing?
- Observe working conditions through process and document review and by interviewing staff;
- Observe waste disposal procedures to identify potential soil, water or air contamination pathways that may affect local communities;
- Review the company's history of community engagement and look for evidence of meaningful dialogue that takes into consideration the community's concerns about human health impacts of the facility.

ACTION PLANS

Any lending or investment should take place within the context of Environmental and Social Action Plans. Typically plans include:

Environmental, Health and Safety Action Plan

- Provision of a financial plan and budget for management of environmental issues and performance improvement;
- Establishment of clear roles and responsibilities for environmental, health and safety issues;
- Development of key performance indicators and monitoring systems to allow for the setting of performance targets to meet regulatory standards and industry best practice;
- Setting of timescales for the achievement of performance targets;
- Development of plans and procedures for managing environmental issues including materials storage, materials handling, emergency response procedures (including spills) and waste disposal;
- Development of a training plan for site personnel to ensure awareness of material environmental issues;
- Development of a schedule and procedure for review and updating of the action plan.

At some facilities, additional measures such as the following may be appropriate:

- Undertaking CFC, PCB and asbestos surveys of all the equipment and facilities, and;
- Implementation of noise mitigation measures.

Social, Labour and Community Action Plan

- Design and communicate an appropriate code of business conduct that considers concerns of key stakeholders (shareholders, employees, government bodies, NGOs);
- Implement best-practice labour standards (in line with ILO principles); consider signing up to international frameworks such as the UN Global Compact;
- Development of plans and procedures for managing social issues including community health impacts and working conditions;
- Implement a process to assess labour and human rights conditions for contractors and sub-contractors;
- Design a robust and on-going community engagement process to measure and report on impacts (positive and negative) on local communities;
- Considering measuring and communicating wider socio-economic impacts (such as job creation or infrastructure development) – for example using the World Business Council for Sustainable Development Measuring Impact Framework.

REFERENCES AND ADDITIONAL SOURCES

Agency for Toxic Substances and Disease Registry - http://www.atsdr.cdc.gov/

Department of Trade and Industry Refrigeration and Air Conditioning CFC and HCFC Phase Out - http://www.berr.gov.uk/files/file29101.pdf

European Union environmental legislation - http://europa.eu/scadplus/leg/en/s15000.htm

International Finance Corporation Environmental, Health and Safety Guidelines - http://www.ifc.org/ifcext/sustainability.nsf/content/EnvironmentalGuidelines

Inter-governmental Panel on Climate Change - http://www.ipcc.ch/

International Labour Organisation - http://www.ilo.org/global/lang--en/index.htm

Semiconductor Industry Association: Environment, Health and Safety - http://www.sia-online.org/cs/issues/environment_safety_health

UK Environment Agency Pollution Prevention Guidelines - http://www.environment-agency.gov.uk/business/topics/pollution/39083.aspx

United Nations Environment Program: Montreal Protocol on Substances that Deplete the Ozone Layer - http://www.unep.org/ozone/pdf/Montreal-Protocol2000.pdf

United States Environmental Protection Agency - http://www.epa.gov/

WBCSD Measuring Impacts Framework - http://www.wbcsd.org/templates/TemplateWBCSD5/layout.asp?type=p&MenuId=MTU3Mw