Magnetic Field Interference - A Rising Consideration for Semiconductor Fab and Process Tool Design

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Keywords: Magnetic Field, Contamination Control, Impacts, EMI Requirements, Measures, Fab Design

Abstract. Magnetic fields have been well known as a potential source of disturbance for sensitive electron-optical process tools for many years. Until recently, these effects were mainly limited to research applications or small laboratory areas in semiconductor fabs analysing leading edge process technologies. However, due to the increasing levels of power demand for process tools and facility systems in combination with decreasing structures and the widespread applications of electron optical processes in metrology tools, EMI (Electron-Magnetic Interference) limits have started to more strongly influence wafer fab and process tool design. This article addresses the latest requirements of process technology and process tools, informs the reader about the relevant sources of magnetic fields in high-tech fabs, and outlines state of the art measurement technologies and procedures to control these fields.

1. Introduction

Due to the fact that magnetic fields cannot be seen or felt, for most people they are incomprehensible or even mysterious. Let me try to bring a little bit of light into this topic. Magnetic fields are characterized through frequency and intensity. Up to app. 30 kHz magnetic and electrical fields are separated and bounded to the generating source. For higher frequencies both fields are coupled and they can travel via big distances. The frequency range starts from a few Hz (e.g. power supply) , 10^5-10^8 Hz (Radio, Television), 10^{14} Hz (visible light), 10^{20} Hz (gamma rays) up to 10^{23} Hz (cosmic radiation) . Electromagnetic fields are used in many ways in our daily life (radio, television, mobile phone, WLan, Blue tooth, etc.) to transport information and to make our lives easier. These applications have made our lives much easier, but due to their interaction with the environment, they can cause problems for human health and also disturb process tools for high tech production. This is mainly caused due to the deflection of electrons in the presence of magnetic fields. Electrons or charged ions are responsible in our body for transportation of information, and electrons are used in semiconductor process tools for photo or metrology applications. In high- tech industries such problems are known as EMI = Electro Magnetic Interference. Due to the fact that especially very low frequent magnetic fields (DC-30 kHz) have already influenced and will further influence fab design in the next years, this article is limited onto this frequency range. The next chapter informs about typical impacts and damages.

2. EMI Impacts/damages

Electron-optical devices are widely used in semiconductor industry. They use electrons or charged ions to transport an image from a pattern (e.g. reticle) to a product (e.g. wafer) or they use electrons to examine small structures. In both cases a set of magnetic lenses is needed to collimate the electron beam (**see figure 1**). In the presence of an outer disturbance field, this collimation process will be disturbed and the resolution will negatively be influenced.

The following devices are mainly affected:

- Electron Microscopes (EM)
- SEM (Scanning EM;
- TEM (Transmission EM)
- Metrology tools (using electron-optics)
- E-beam tools (e.g. mask writers)
- Focused Ion Beam tools (FIB)

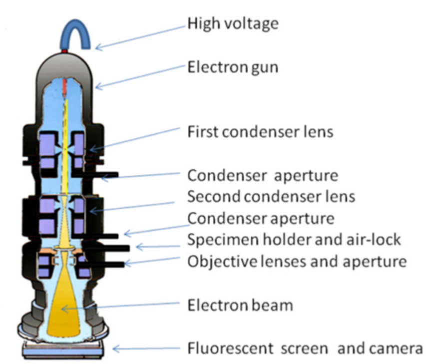

Figure 1: Principal sketch of TEM (***Graham Colm***)

Typical sources of magnetic fields in semiconductor industry are listed in **table 1**.

Source	Frequency	Size	Critical for Semiconductor Fab/Lab	Possible measures
Earth Magnetic Field	DC	30-60 µT	no	not necessary
Movement conductive masses in earth magnetic field (truck, elevator, subway, chair)	0-10 Hz	Example Truck in 12 m distance: 100 nT	yes	distance; shielding difficult; active compensation
Process Equipment Magnetic Annealing Tools	DC-mHz	500 -1000 µT	very critical	distance, shielding
High Power Lines (example 115 kV line ;2x350A)	50-60 Hz	100 nT in 60 m distance	yes	distance, shielding
Electric energy supplies, power supply, transformer	50 Hz-1 kHz	8-500 µT	very critical	layout, metal shielding
Motors and generators	50 Hz-1 kHz		yes	distance, shielding
Contactless charging OHT	8kHz-9 KHz		yes	distance, shielding

Table 1: Main EMI sources (0Hz-30 kHz)

Two typical EMI problems were kindly placed to our disposal from IMEC, the world leading R&D and innovation hub in nanoelectronics and digital technologies, located in Leuven, Belgium.

Example 1: The analytic capability of IMEC was expanded through an additional electron microscope (TEM 3), which was placed adjacent to an already existing one (TEM 2). See **figure 2**. After start-up the resolution of the TEM 2 (spec 80 nT rms) was disturbed through a 50 Hz magnetic field. Magnetic field measurement indicated that the transformer of TEM 2 was responsible for the disturbance field (**see figure 3**). The existing TEM 2 used an active compensation to minimize fields from the transformer. At the end a relocation of the transformer (10 m away) solved the problem.

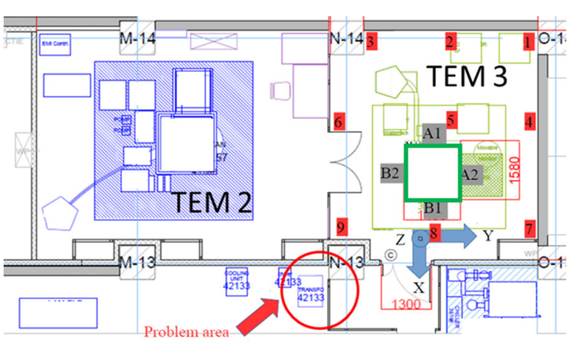

Figure 2:Location of TEM 2 and 3

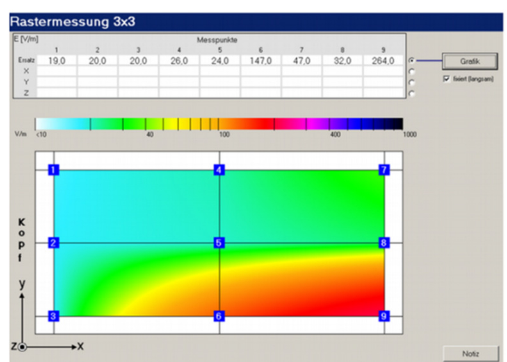

Figure 3: Measurement results in TEM3 (***Rolf Mennekes; 2017***)

Example 2: A new magnetic annealing tool should be integrated into an existing IMEC production area. The annealing process requires very strong magnets, which are ramped up and down (0-5 T). This process generates slow changing DC magnetic fields, which can disturb SEMs and TEMs. A separate measurement of the ramp-up process was executed at the process tool manufacturer site. Based on this measurement, a location with a min. distance of 53 m to sensitive SEMs/TEMs was found to prevent magnetic interference (see **figure 4**).

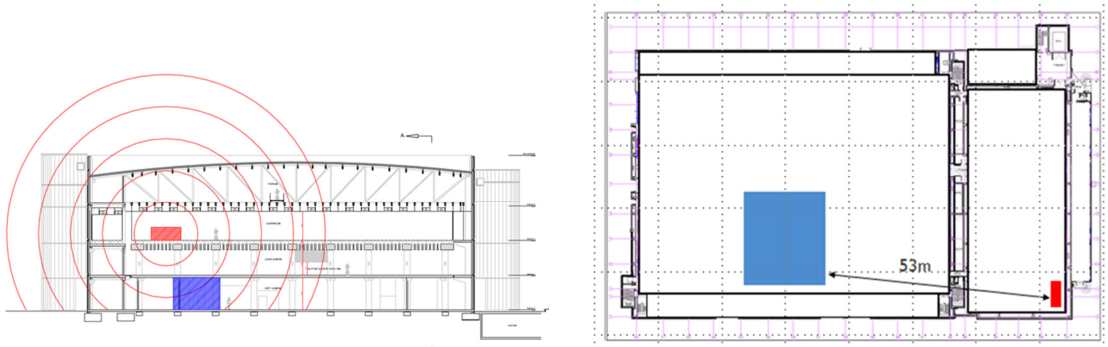

Figure 4: Location of annealing tool (section/top view; ***Wim Vansumere IMEC 2018***)

3. Raising EMI Requirements

In the subsequent chapter the results of an M+W induced EMI analysis was described. The goal of this analysis was to find out if and how the EMI requirements for semiconductor fabs have been changed during the last years.

3.1. ITRS roadmap

Parallel to shrinking feature sizes of microchips also the sensitivity according magnetic field levels raised continuously. For the first time 2013 ITRS integrated magnetic field limits in their facility requirement table **(*ITRS 2015*).** The following table informs about raising EMI requirements depending on time and technology node. See **figure 5**. Included are also the tightest EMI specs for wafer and reticle inspection

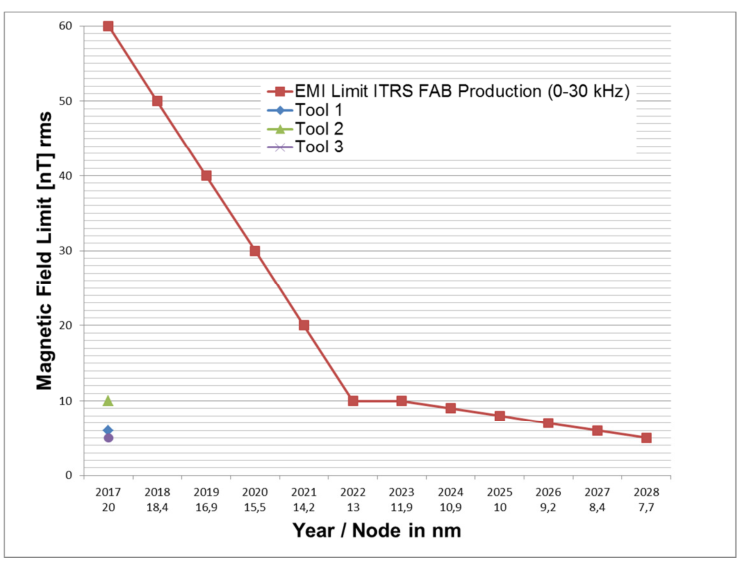

Figure 5: Raising EMI requirements (time and technology node)

3.2. Process / Process Tools

The following listing informs about typical EMI Fab requirements and the tightest EMI process tool specification (base M+W Fab/Tool database) in semiconductor industry.

Production area
AC/DC* 0Hz-30kHz <= 100 nT RMS (app. 300 nT p-p)
Lab area
AC/DC* 0Hz-10kHz <= 10 nT RMS (app. 30 nT p-p)
Tightest Spec
AC/DC* 0Hz-10kHz <= 3.5 nT RMS (app. 10 nT p-p)

* Slowly changing magnetic fields e.g. generated through movement of conductive materials in earth magnetic fields

New Trend: But not only specific EMI process tool specification raised due to shrinking feature sizes also tool manufacturer have started to shift process steps from optical imaging towards electron optical imaging (e.g. mask inspection, wafer inspection). Therefore much more process tools will get sensitive according magnetic fields. Consequently biggest metrology process tool manufacturer have started to protect their most sensitive metrology tools through additional shielding chambers.

An additional analysis of the process tool sets of existing semiconductor fabs was done to analyze quantity of EMI sensitive process tools. This analysis also confirms a raising percentage of EMI sensitive process tools over time (see **table 2**).

Manufacturer	Year	Qty tools	Percentage of EMI sensitive Tools	Tightest spec	Remark
Manufacturer 1 (USA)	2017	793	9,0%	176 nT	18,5 % of photo tools are EMI sensitive; not included support, Lab or test tools
Manufacturer 2 (Asia)	2015	859	6,5%	35 nT	56,5 % of photo tools are EMI sensitive; not included support, Lab or test tools
Manufacturer 3 (Asia)	2015	840	4,0%	176 nT	not included support, Lab or test tools

Table 2: Percentage of EMI sensitive process tools for existing semiconductor fabs

3.3. Raising Fab energy demand

On the other hand a raising energy demand inside semiconductor fabs has to be stated. This raising energy demand is based on increased tool power requirements, improved packing density and raised cleanroom load (heat) and PCW /Chilled Water capacity. All these facts lead to a higher energy demand per m^2 manufacturing area and therefore also to a higher background magnetic field level (see **figure 6**).

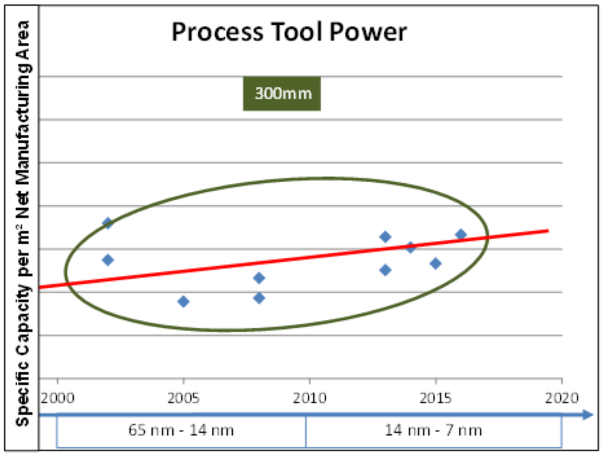

Figure 6: Process tool power demand requirements

Area	Change of EMI Requirements	Remarks
Process		Smaller geometries require higher resolution; higher resolution require higher EMI sensitivity (electron optical devices)
Process Tools		Process tool manufacturer dampen the above described EMI sensitivity increase through better internal shielding and external EMI chambers/enclosure (active/passive)
Qty of EMI sensitive process tools in production area		Due to smaller geometries, existing optical processes in production line needs to be replaced through electron optical processes (sensitive against EMI)
ITRS Roadmap		ITRS roadmap exepects increasing EMI fab requirements
Energy demand process tools		Energy demand of process tools will increase through introduction of EUV technology. Higher enery demand is equivalent with higher current and higher EMI emissions.
EMI pollution of site and Fab		Wireless datacommunication is more and more entering semiconductor Fabs. Therefore RFI emissions will increase

Table 3: Summary: Raising EMI

Not included in this graph, is a further increase of power demand through a future introduction of EUV lithography technology.

It can be summarized (see also **table 3**) that we have to deal for future fab design with a clear trend to tighter EMI Fab specification combined with a raising level of disturbing background level of magnetic fields.

4. Holistic EMI Approach

These raising magnetic field specifications have to be considered mainly in high-tech industries where nano-structures have to be generated, processed or visualized. This is valid for semiconductor industry, research or nanotechnology.

In order to satisfy these magnetic field requirements a holistic approach is strongly recommended. The success to create an optimal environment for the operation of EMI sensitive tools depends on the interaction of Fab designers, Shielding Chamber specialists and tool designers. At the end the reachable magnetic field level inside the tool during the process is important. This has to be guaranteed through the following protection levels (see **figure 7**):

Fab protection: EMI concept has to assure, that 80-90% of process tool specs are fulfilled (ITRS roadmap)

Tool Protection
For very sensitive tools additional shielding measures are needed

Process Protection
Basic process protection is required during tool design

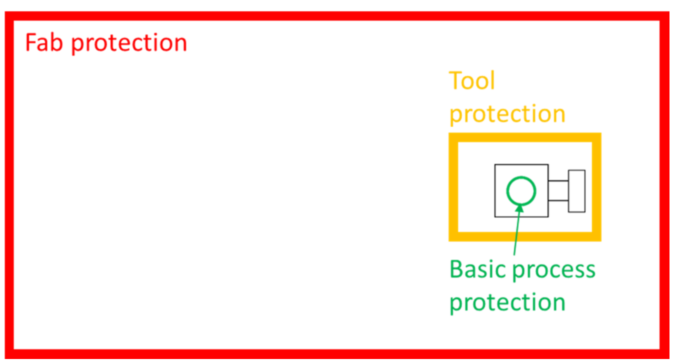

Figure 7: EMI protection levels

The following subchapters informs about possible measures to minimize magnetic interference.

4.1. Fab protection

A very effective way to minimize magnetic field levels is to raise distance between the source and the sensitive area. The decay of the magnetic field can be estimated using the following approximation (see Eq.(**1**)):

Power supply: one phase	$B \sim \frac{1}{r}$	
Power supply: three phases (***Daniel Genz 1999***)	$B \sim \frac{1}{r^2}$	(1)
Power supply: three phases (twisted cable; ***Daniel Genz 1999***)	$B \sim \frac{1}{\sqrt{r} e^r}$	
Transformer (***Alber***)	$B \sim \frac{1}{r^3}$	

Another possibility is to minimize magnetic emissions directly at the source. Following are listed main guidelines:

- Reduction of magnetic field generation of power supply lines through “Cancellation”. Supply and return wires of power supply lines generate magnetic fields which will cancel each other, if they will be guided side by side.

- Use twisted cable in sensitive areas. Twisted cables will help to better cancel magnetic fields generated via supply and return wires.

- Use twisted cable with concentric earth conductor for currents > 150 A (prevention of induced voltages due to unsymmetrical load of phases)

- Do not use busbar power distribution systems in EMI sensitive areas. Busbar systems needs more space between the different phases compared to cable guided power supply and therefore magnetic generation is higher.

It is reasonable to think of a specific room or area shielding (see **figure 8**), if only a specific area or room has to be protected. This can be useful for existing Fabs or Labs, where a process upgrade leads to tighter EMI spec. Depending on the required frequency area, materials with high conductivity (e.g. Aluminum) or with high permeability (e.g. µ-metal) have to be chosen. If possible, also shielding of the EMI sources can be taken into consideration (e.g. shielding of transformer or cable trays). **Figure 9** represents an EMI simulation of such a shielded area.

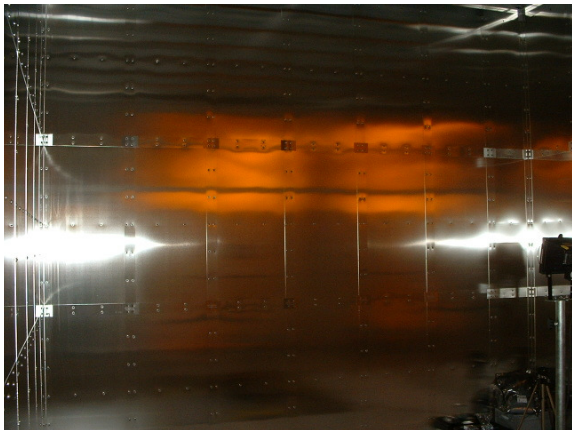

Figure 8: Shielded room

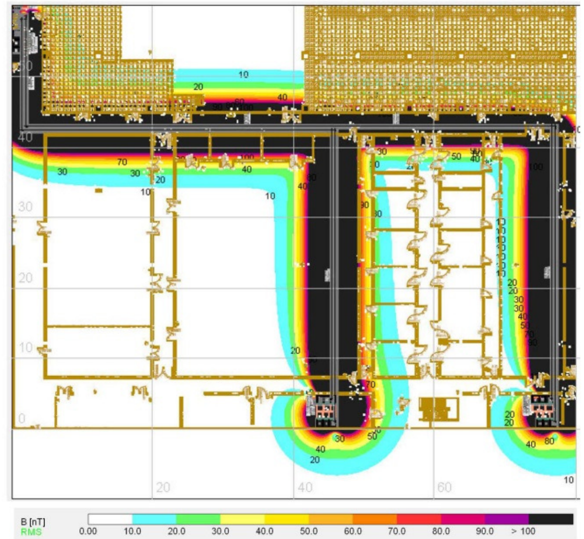

Figure 9: EMI simulation of a shielded area

4.2. Tool protection

As described EMI protection is a common effort, therefore what can be done to further protect an EMI sensitive tool? Since a few years M+W was ordered from the leading semiconductor metrology manufacturers to develop for their most sensitive tools specially adapted shielding chambers. In most cases these chambers have to fulfill not only EMI specification, they also have to protect against airborne particles, acoustics and temperature gradients. Such shielding chambers are often a compromise between absolute protection and reasonable maintenance access. Depending on the required shielding factors active (flux compensation) and passive shielding (chamber wall material consisting of shielding material) technologies will be used to realize the required protection. **Figure 10** depicts a shielding chamber for acoustic and magnetic field shielding (µ-metal). **Figure 11** illustrates an EMI simulation during conceptual design. The chamber in **figure 12** assures acoustic, cleanliness and EMI specification using active flux compensation. **Figure 13** represents a chamber which controls acoustics, temperature, cleanliness and magnetic field limits using active and passive shielding techniques in one chamber.

Figure 10: Shielded Enclosure

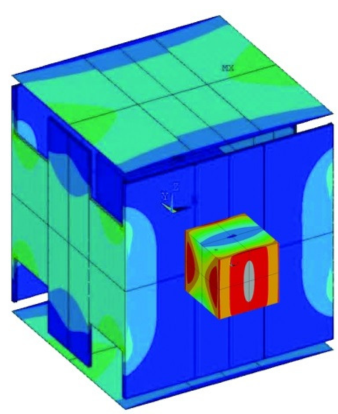

Figure 11: EMI Simulation shielded enclosure

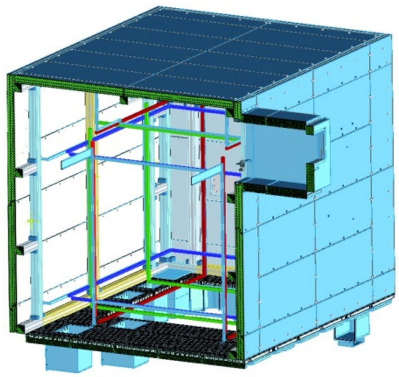

Figure 12: Shielding Chamber with active flux compensation

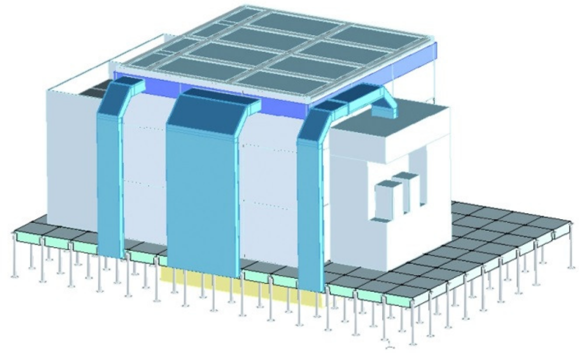

Figure 13: Shielding Chamber (active/passive)

4.3. Process protection

A basic process protection will typically implement through the designers of the process tool manufacturer. Typically the electron gun is protected with a separate shielding layer, the flow of current near the process chamber will be reduced via power supply with high voltage and/or through the internal process tool layout (max. distances between EMI sources and sensitive area). Nevertheless the complete process cannot be protected, because the product needs to enter the process area. Therefore, independent from the efforts of the tool designers, there is still need for minimizing magnetic fields (e.g. via shielding chambers or EMI reduced fab areas) in the neighborhood of such process tools.

5. Conclusions

On the last pages arguments were depicted that the EMI requirements of semiconductor process and process tools have already increased and will further increase.

Also the energy demand of future semiconductor fabs (especially with EUV technology) will increase and therefore the pollution with magnetic fields will rise.

These impacts of magnetic fields on future semiconductor processing are recognized from the leading manufacturer of microchips and process tools incl. the ITRS roadmap.

Therefore the fulfillment of EMI requirements will be one of the key requirements of future Fab and Tool design in order to reach expected performance or yield.

A holistic approach is needed to synchronize the efforts from Fab, chamber and Tool designers

We would like to thank Mr. Wim Vansumere from IMEC, who provided us two examples of EMI impact scenarios in real manufacturing environment.

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