The RF Excited Plasma: RFI/EMI and Safety Considerations

Introduction

Many years ago, sputtering was a nuisance phenomenon that limited the lifetime of spectrum tubes. Some sputter depositions were commercially interesting, but the hardware left much to be desired. In particular, since the excitation was by direct current in the "glow discharge" mode, pressures were necessarily high. Typically such plasmas operated at pressures in the hundreds to thousands of Pa (that's, perhaps, 100 to 400 mTorr or, in those days, "microns" --- for micro-meters of the height of the column in a mercury manometer. At such elevated pressures, the mean free path was almost always *much* shorter than the source-to-substrate distance. Thus, a sputtered atom would experience many collisions before it could possibly be collected by the substrate.

To make matters worse, such pressures were much too high for continuous operation of diffusion pumps, so the systems were often pumped with simple mechanical pumps. (Can you say, "Backstreaming!" and "Contamination"?) Small wonder that evaporation techniques were still in common use for metallizations well into the 1960s!

But, in about that same time frame, RF diode sputtering was commercialized. These systems could be operated at pressures in the few Pa range, thus *barely* allowing diffusion pumps, turbomolecular pumps and cryopumps to be used.

The "learning curve" was, to put it charitably, *interesting*. The history of all this borders on the down-right amusing, but this is neither the time nor place, so:

For context, we need to inject some of the "practical considerations" along with the engineering-physics: Most sputter deposition is performed using an excitation frequency of 13.560 MHz. There is nothing particularly magic about this selection... it is one of the ISM (Industrial, Scientific, Medicine) frequencies that has been assigned by international agreement for such purposes. Other ISM frequencies in this general part of the E-M spectrum are: 27.120 MHz (think: garage door openers, approximately, and CB radio) and 40.680 MHz. Your microwave oven probably operates at another: 2450 MHz, and there is yet one more at 915 MHz.

At these precise frequencies, ± a very small deviation, you are allowed to radiate almost without limit (except for safety) because there are *no other services* such as land-mobile communications or TV stations on those precise frequencies. That is: The assignation of these ISM frequencies is solely a matter of possible interference with other services.

You can use any frequency you like, of course. What you lose, however, is the freedom to radiate. Non-ISM frequencies are subject to *very stringent limits.*

A moment's consideration will reveal that the second two (lower) ISM frequencies are harmonics (n=2 and n=3) of the lowest ISM frequency. Why is this important?

The V/I characteristics (voltage/current) of a plasma look a lot like those of a diode. Since we are therefore dealing with a very non-linear load, we must expect a high level of harmonic generation. That is exactly what happens. Now, if you are a "Ham" radio enthusiast, you will probably recall that the "odd" harmonics (n=3, n=5, etc.) are usually present at substantially higher levels that the "even" harmonics (n=2, n=4, etc.) in the output of an RF amplifier.

For a plasma load, this is **not the case.** Harmonics up to n=20 are easy to detect, and those frequencies are used by a broad range of services. For example, assuming that f_0 (the excitation frequency) is 13.560 MHz, then the n=4 harmonic is 54.240 MHz. That particular frequency is right on top of the sound portion of TV Channel 2. Other commonly strong harmonics may interfere with Channel 6 and Channel 7. The n=8 harmonic is in the FM Broadcast Band and n=9 and other harmonics lie in the aircraft VHF communications band. ("United 135 Heavy, Bay approach: Say again. You're being interfered with...") I'm a (private) pilot... I actually heard this. The carrier for the interfering signal carried the unmistakable modulation of marginally filtered three-phase power... most likely from a sputtering tool.

Translation: RFI/EMI shielding is **always** required on **any** sputter system (or similar plasma device) with RF excitation. Using an ISM frequency simply makes the job a little easier.

Etching, both simple physical ("sputter etch") and the many varieties of "chemical" plasma etch configurations, may use very different frequencies. So-called "ashers" (a reactive plasma is used to "burn" photoresist) generally operate at much lower excitation frequencies... typically tens to hundreds of kHz. Other reactors designed for similar tasks, may operate in the microwave band. One manufacturer [Plasmatic Systems, Inc.] even sells a plasma cleaning device that is built inside a microwave oven! (It's remarkably easy to do... and patented!)

Standards for RFI/EMI

RFI: radio-frequency interference

EMI: electro-magnetic interference

There are any number of standards with which you, the user, must contend. It is **NOT** wise to assume that the manufacturer of your equipment has properly addressed these concerns. Aside from that, even if they did, the responsibility in the US at least, is **YOURS** and relates to the system *as installed*. There's a perfectly good reason for this, as it happens: The interference that may be radiated from a piece of RF equipment may depend strongly upon how and where it is installed. There simply is no way for a manufacturer to be 100% certain that there will not be an unacceptable level of interference from your device until it is installed. Why is this? Here are a few possibilities:

- There may be some loose screws from vibration in shipping.
- The soil under your facility may have a high resistivity.
- You may not be on the ground floor.
- Electrical power feeds may act like antennae.
- Parts of your building may act like reflectors for some frequencies
- Etc., etc....

You *should* be able to get some useful assistance from the manufacturer, but don't count on it. The knowledge is quite specialized, the required diagnostic tools are expensive, and many manufacturers simply don't care very much... particularly when their legal liability is generally in the NMP (Not My Problem) category.

As you must realize by now, standards generally address one of two issues; namely,

- Interference with other services, and
- Safety

It is generally pretty clear as to what "interference with other services" means... somebody else can detect your signal where it is neither desired nor supposed to be! In some cases, that party may be rather tolerant and nothing will happen to you, but in others (try interfering with a "soap opera" on TV!) formal complaints may quickly be filed.

Safety issues generally fall into one of two categories; namely,

- Shock hazards, or
- Absorbed radiation hazards

Use the word "radiation" and many people lose all resemblance to intelligent life. Radiation, of course, is all around us and always has been. Some forms are quite safe at suitable levels while others are incredibly dangerous. How to tell which is which?

For most low frequency RF, the primary hazard is usually electric shock. As the frequency goes up into the MHz range, skin effect becomes important and "rf burns" may be more of an issue. As the frequency extends through the hundreds of MHz into the GHz range, the hazard becomes power absorption that, in turn, results in heating. (Think: microwave oven, where f_0 = 2.45 GHz) At this point, we are far too low in frequency to need to be concerned about *ionizing radiation.* Ionizing radiation is, of course, what most people envision when you use the word "radiation."

Shock Hazards: Zapppp!!

Seriously, electric shock can be fatal, and a cavalier attitude has no place in the lab or the fab. What is not always appreciated is that RF has some special features that make it a little more dangerous in some ways (...not to revive the old Thomas. A. Edison / George Westinghouse controversy over the relative dangers of AC and DC! If that doesn't ring any bells, may I heartily recommend Ira Flatow's book "They all Laughed...from Light Bulbs to LASERS", Harper Trade, 1933.)

Corona ("crown") is a type of "silent" electrical discharge (it isn't entirely silent... there is an definite hiss!) wherein the air surrounding a high voltage element becomes partially ionized and therefore partially conductive. For AC at power line frequencies, the positive space charge cannot be collected within one period of the driving potential, and so contributes a little extra electric field to the following cycle. This goes on until equilibrium is reached.

At high frequencies, various diffusion and transport mechanisms come into and go out of play, but the idea is the same; namely, AC and RF are different "beasts" from dc.

Nowhere are "line power" AC and RF "more different" than the matter of power, current and voltage. We will return to that in detail in a later topic, but for now, it is important to understand that **BOTH** very high voltage and very high current may be present at the same point in an rf circuit, even though the available power is small.

Be careful!

Absorbed Power and Concomitant Heating:

Generally, the amount of power absorbed from anything short of looking into an open wave-guide (BAD IDEA!! NEVER DO IT!) is small. Thus, intuition would suggest that the hazard due to absorbed RF radiation is so small as to be negligible.

Intuition would be wrong.

Some parts of the body are quite sensitive to temperature, such as the brain, eyes and the reproductive organs. We get something like the equivalent of heat stroke when we overheat the brain... or dead if we overheat it just a bit too much. We get cataracts years later if we overheat the eyes... or blind if we do so to extreme. I leave it to your fertile (pun intended) imaginations as to what happens to the latter organs.

Federal Communications Commission (FCC)

The FCC controls emissions from ISM equipment under various provisions of Part 18. The complete specification can be found online (in PDF format) at: http://www.rbitem.com/emcstandards/northamerica/FCC%2047CFR%20part%2018.pdf

Verband der Elektrotechnik Elektronik Informationstechnik e.V. (VDE)

Historically, while other countries worried primarily about operators "glowing in the dark" after their shift, VDE developed a reputation for being the most stringent standards in the world. The German Post Office administers these standards.

VDE publications and Standards are available from their publishing arm, VDE Verlag at: http://www.vde-verlag.de/

International Special Committee on Radio Interference (CISPR)

CISPR is a non-governmental group administered by the International Electrotechnical Commission (IEC) as well as many other organizations with regulatory interest.

IEC documents are available for purchase on the Web at: http://www.iec.ch/webstore/

Occupational Safety and Health Administration (OSHA)

This US agency, operating under the Department of Labor, addresses workplace safety issues only. A wealth of information can be found on their Web Site at: http://www.osha.gov/

A good place to start would be to perform a search on "non-ionizing radiation" and look at what they have to offer.

Canadian Standards Association (CSA)

If you want to send a piece of equipment to Canada, you will become intimately familiar with these standards. Assuming that you are not an equipment manufacturer, CSA might become an important issue for you if you plan to send some equipment to your laboratory in Canada. If you are not a "safety standards professional", whatever that may mean, you should probably hire a consulting company that specializes in CSA and listen carefully.

The CSA Web Site may be found at: http://www.csa.ca/

Summary

If you own and/or operate any thin film process tool with an rf-excited plasma, it is likely that you will encounter RFI/EMI. Contrary to what might be expected, the responsibility lies not with the equipment manufacturer, but with the owner/operator. As such, it behooves you to familiarize yourself with the requirements of both the Law and common sense.

There are a number of good free resources, and there are many consultants who are decidedly not free.