DOSIMETRY DESIGN CONSIDERATIONS FOR SERIAL AND BATCH ION IMPLANTATION SYSTEMS

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Dosimetry systems for serial and batch ion implanters have evolved from simple current - time integrators, to complex sampling systems offering a high degree of in-situ dose control and correction capabilities during the implant. Advanced device designs and a larger cost per wafer, require a higher degree of control over implant parameters such as implant angle, dose, uniformity, repeatability, and beam (energy) purity.

The introduction of higher beam currents brought with it the need for electron flood systems to control surface charging of the wafer. Furthermore, the need for a more precise determination of the implanted dose requires dosimetry systems to be immune to secondary charged particles generated during the implant process.

The trend towards larger wafer sizes (≥200 mm) places constraints on the use of the wafer itself in the dosimetry system, because the size of the wafer prevents adequate suppression of secondary electrons generated by interaction of the ion beam with the wafer surface.

In this paper various conventional approaches to measuring the actual dose of the ion implantation process will be presented. The paper will focus on the complexities of dosimetry systems that not only have to measure dose and uniformity, but simultaneously have to allow for variations in tilt angle, ensure beam parallelism, allow for wafer loading and cooling, and be immune to secondary electrons generated by the implant or by a charge neutralizing system.

1. INTRODUCTION

Ion implanter dosimetry systems consist of two major parts: a system that collects information about the arrival rate of dopant at the substrate, and a system that ensures that the dopant is uniformly distributed over the target surface. On all commercial implant systems on the market today, the monitor for the dopant arrival rate consists of an electrostatic Faraday system collecting the charge carried by the ion beam. In principle there are several ways in which the dose of an implantation could be measured.

One alternate method is to observe secondary X-rays, generated by the collision of ions with atoms in the substrate [1]. Another method uses the calorimetric temperature rise caused by the power of the ion beam hitting the substrate [2]. A third alternative uses a tungsten wire inserted into the beam path which generates secondary electrons [3]. These electrons are collected on a pickup plate and the fluency is monitored. In a fourth alternative method [4] the ion beam passed through a 400 Å gold foil. Rutherford back scattered ions are collected, and used to determine the beam intensity.

All these dosimetry methods have been studied, and they could in principle be employed or combined with existing dosimetry systems. The main reason that these methods have not been used is that charge collection is easier to use.

2. COLLECTION OF ION BEAM CHARGE

The principle of collecting the charge in an ion beam is fairly straightforward (Fig. 1). Positive ions from the beam are neutralized by electrons coming from ground. The dose D, implanted by ions with charge q, striking an area A, during a period T, with a beam current I_b, is given by [5]:

$$\int_{t=0}^{T} I_b(t)\, dt = q \cdot A \cdot D \tag{1}$$

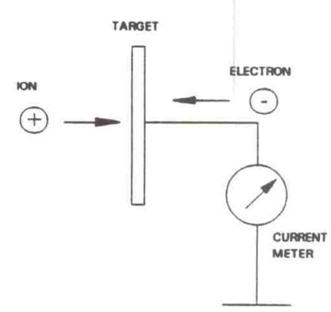

Fig. 1. Principle of ion beam charge collection.

This dosimetry formula underlies all charge collecting systems. Implicit assumptions are that I_b is equal to the dopant arrival rate, that all ions have charge q, that all ions are dopants also, and are not reflect from the target in an elastic collision, that the electronics perform the integration correctly, and that the implant area A is well determined.

There are some invalidating conditions that require attention. An ion beam in a vacuum system also contains low energy electrons (that provide space charge neutralization), neutrals (energies between a few eV up to the primary ion energy), and ions at different charged states and energies.

Beam transport allows for the arrival of a mixture of particles (e.g. N_2^+ in a $^{28}Si^+$ beam), charged states (e.g. P^+ in a P^{++} beam), and energies, conceivably distributed unevenly over the target and contributing to the current measurement [2,5].

Furthermore, the impact of the ion beam on the target and on beam line apertures releases secondary particles (ions, electrons, neutrals and photons) that can generate tertiary particles by colliding with the surrounding environment, which can re-deposit on the target. These contributions are not negligible: the secondary electron yield is 2 to 20 per incident ion, the neutral yield is 2 to 20 per ion, and the ion yield is 0.01 to 0.2 [5].

The implant area A has to be well defined to get a reliable dose measurement [5,6]. The defining aperture- of the Faraday system or of the implant area determines where the ion can hit the target. However, changes in beam spot size of the center of scan, lead to a penumbra effect [7] that makes the edge of the implanted area less well defined.

Suppression of beam line electrons can be achieved with either an electrostatic or magnetic field [8]. These fields will prevent electrons in the beam from hitting the target, and they will prevent secondary electrons from leaving the Faraday.

Faraday suppression systems will not stop the impact of neutral atoms, which can result in overdosing, non uniformities, and implant depth variations, particularly in the case of (local) high system pressures. Further, negative electrostatic suppression will not prevent positive ions from leaving the Faraday (Fig. 2), which is the reason that electrostatically suppressed Faraday cups are generally deep. Secondary particles hitting the suppression electrode can generate charged tertiary particles that can accelerate to the target, where they can induce charging damage.

Electrostatic fields can also lead to beam blow up, which can result in uncertainty of the implanted area or of beam position and shape. The beam potential in itself creates a leakage path for secondary electrons and ions [9] by reducing the effective voltage in the center of the suppression electrode.

Magnetic suppression will also stop low energy ions if the field strength is high enough. But magnetic suppression can also let positive ions escape, if the force on the ion by the magnetic field is compensated by the force from the electrical field of the ion beam (as in an ExB filter).

Both magnetic and electrostatic suppression Faraday systems have been shown to provide pressure independent results [10,11].

Faraday designs are further complicated by the need to supply additional low energy electrons to the target to prevent charge up of insulating surfaces. These electron flood gun systems (EFG's), are sometimes built into the Faraday system itself or are located in front of the target. Care has to be taken that the energy of the secondary electrons is low enough to prevent charge damage.

Most EFG systems also utilize a gas bleed system to provide additional low energy electrons by interaction of the primary ions with the gas. The additional gas pressure increases the neutral portion of the beam, and if this charge exchange happens outside the Faraday it will not be picked up and hence

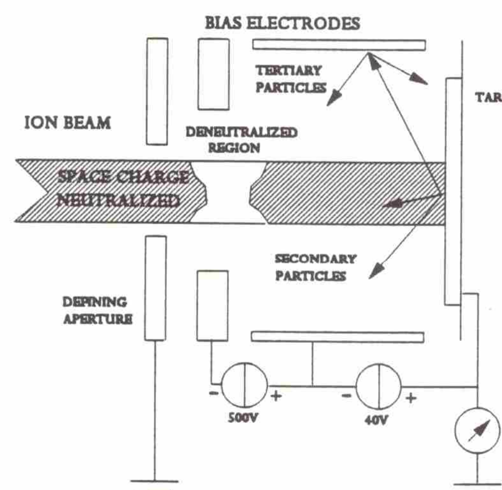

Fig. 2. Arrangement of double suppressed Faraday.

it will offset the measured current.

The Varian E1000 incorporates both the EFG and a gas bleed into the Faraday system. This means that any charge exchange, from an ion to a neutral inside the Faraday is accounted for. The Eaton NV20A, besides using an EFG and a gas bleed, also uses a hot cathode ionization gauge to compensate for the effect of additional neutrals.

Care has to also be taken in the electrical isolation of the various components of the Faraday system. Leakage paths through insulators or cooling water can cause erroneous current measurements. Openings around the target area that are needed to accommodate wafer handling, or high angle tilt and rotate motions of the wafer can allow secondary particles to escape.

Another important factor that has to be considered when measuring the dose is the accuracy of the charge integrating electronics [6]. The dynamic accuracy of the integrator has to be sufficient to give accurate current readings even when the instantaneous beam current is significantly higher than the time average. A complicating factor is that the beam current ranges over more than 6 decades. This means that the integrator has to be immune to electrical noise, have no zero offset, and be linear over a very large range of currents.

3. SCAN SYSTEMS FOR UNIFORM DOPING

The dopant has to be uniformly spread out over the wafer surface with variations of sometimes less than 0.5% to get proper device performance.

Today's implanters all use some form of scanning to achieve uniform doping of the wafer. The overlap of individual Gaussian beam profiles has to be better than 1.5σ beam diameter for 1% uniformity, and the overscan at the wafer edge has to be 3σ [12,13].

Charge collecting dosimetry systems can be catagorized in several ways. One way is identify them according to whether (part of) the wafer is internal or external to the Faraday system. Another classification is to look at whether the beam is swept across the target or whether the target is swept across the beam (hybrid scan systems sweep both target and beam at the same time). A third classification is whether a continuous integration of the beam current is used, or whether the beam is sampled at intervals (in which case the total dose is extrapolated from the sample). One last way to catagorize is according to the dose control system.

An open loop control system integrates the scanned beam until the preset dose is reached, without any corrections in the scan for beam current fluctuations during the implantation. A closed loop control system, continuously adjusts the scan system during implant according to real time observations of the beam current. Closed loop systems can be subdivided into systems that use position modulation of the scan motion (like the Varian E1000 [14]) to correct for beam current fluctuation, and in systems that use velocity modulation of the scan motion (like the Eaton NV20A [15,16] and the Varian E220 [17]). This is further discussed in section 3b. The different classifications of dosimetry systems are shown in table 1.

3.a. Wafer internal versus external systems

Both wafer internal and wafer external systems have proven to be successful with uniformity and repeatability results of less than 1% [8]. Making the wafer internal to the Faraday system has the advantage that the total scanned area can be kept to a minimum (less overscan required). Furthermore, there is no calibration needed between the Faraday dose and the wafer dose.

Wafer external systems have to sample the ion beam by default, while wafer internal systems can monitor the beam current continuously.

In wafer internal systems, such as the Varian E1000, 180XP, 350D, the Eaton 6200AV, the Nissin NH-20SR, or the Ulvac IPX-7000, the EFG has

DOSIMETRY SYSTEMS CLASSIFICATIONS		
Wafer location	• External to Faraday • Internal to Faraday	
Scan System	• Beam sweeps over wafer • Wafer sweeps through beam • Hybrid: beam and wafer both move	
Integration Meth.	• Continuous current measurement • Sampling current measurement	
Control System	• Open loop • Closed loop	• Velocity Modulation • Position Modulation

Table 1. Dosimetry Classifications.

to be incorporated inside the Faraday system and care has to be taken that electrons do not escape. These systems generally have more apertures in front of the wafer, which can result in larger amounts of sputtered neutrals and ions. Furthermore the presence of an electrical field can strip the low energy electrons from the beam that are needed to prevent wafer charging.

In wafer external systems, such as the Applied Materials PI9200, the Varian E220 and 300XP, the Eaton NV20A, and the Nissin NH-20SP, the EFG has to be located outside the Faraday, and in front of the wafer, with the condition that EFG electrons are kept out of the Faraday so as to not disturb the current measurement. Ion collisions with residual gas in the area in front of the wafer generate secondary electrons which can help to prevent wafer charging.

3.b. Scan systems

All modern high current (>10 mA) implanters use a rotating disk for the fast scan, because this system has proven to give the best results for wafer cooling [7]. The slow radial scan of the rotating disk, can be either mechanical (E1000, PI9200, NV20A) or magnetic (180XP). The Faraday system diameter is typically kept to about the beam diameter, since otherwise suppression of secondary electrons becomes difficult.

The disk has to be scanned through the ion beam with a radial velocity proportional to 1/R to achieve uniformity. The Eaton NV20A uses a precision machined rectangular slot in the disk to sample the beam current [15,16]. The pulse into the Faraday increases proportionally with 1/R as one approaches the disk's center. This increase in current is used to automatically increase the radial velocity (velocity modulation).

On the Varian E1000, a continuous current measurement is used. The dosimetry computer divides the radial direction of the disk in equally spaced small incremental "stripes". Each position of the radial motion will now be exposed to a precalculated dose, after which the disk servo motor steps to the next stripe. This technique is called position modulation.

The slow mechanical or magnetic scan system, uses an measurment of the beam position and beam width to determine the amount of overscan that is needed, and to determine where during the sweep a uniformity correction needs to take place. This is done on the assumption that the ion beam can be thought of as concentrated in a single point (centroid) [18,19]. Liebert [14] calculated that the average dose changes by 0.4% and the uniformity changes by 0.05% (depending on beam shape), if the location of beam centroid is shifted by 2 mm.

The inertia of the scan system introduces a phenomena called "lag-band". The lag-band is the difference between the real position of the ion beam and the position where the dosimetry system assumes it is. In figure 3 we have plotted the lag-band of the E1000 disk as a function of the radial position. When a beam glitch occurs, the radial motion slows down or stops until the scan stripe is filled. This allows the disk to catch up with the assumed position. The overall profile of the curve has a 1/R behavior, reflecting the 1/R velocity change. It is not well understood what effect scan lag has on dosimetry and uniformity.

Medium current implanters (<3 mA) use a variety of scanning techniques, but the electrostatic fast scan seems to be most common. The slow scan can be electrostatic (300XP, 6200AV, IPX-7000) or mechanical (E220, NH-20SP). Uniformity corrections can be done by changing either the fast, or the slow scan profile. In this respect the E220 is rather unique in that it measures the uniformity of each fast scan line prior to the implant, and then changes the fast scan speed to compensate for irregularities during the slow mechanical scan [17].

4. EXPOSURE TO THE ION BEAM

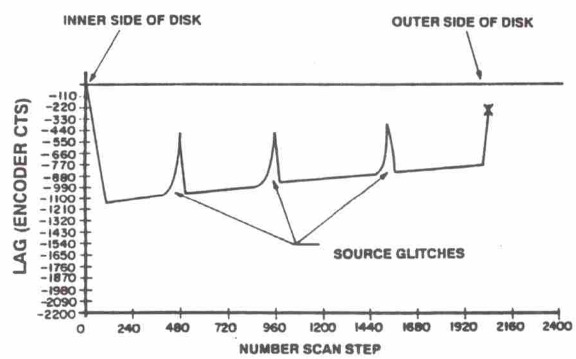

Fig. 3. Scan lag of the disk position in the Varian E1000 as function of time over one mechanical sweep (see text).

Once the ion beam has been set up and is properly focused (usually on a beam dump Faraday cup), the implanter has to expose the wafer to the beam. The exposure is generally preceded by a few measurements that are designed to assure that the correct dose and uniformity will be achieved, such as measurements of beam shape and location of the centroid, scan uniformity, and beam energy purity. Furthermore, the implanter's control computer will take readings of all critical power supply and system settings, and monitor these settings during the implant itself.

During the implant the beam current is integrated until the target dose is reached. However, during the implant, variations in beam current do occur. Extraction-, acceleration-, or source-arc glitches can interupt the ion beam completely. On most older implanters the dosimetry system halts and waits for the ion beam to come back after which the implant proceeds automatically at an arbitrary position on the wafer (open loop control). Newer implanters create a dose uniformity map in computer memory which allows for controlled recovery of interrupted implant. On the E220 one can even exchange ion sources during an implant. The control computer will resume the implant on the scan line where it was interrupted.

Open loop control is acceptable for most glitches in the ion source arc current, but if the ion beam drops out because of an extraction or acceleration glitch it is better to blank the beam in a dump, until it has fully recovered. After an extraction glitch, the voltage recovers with a response time usually of about 2 seconds. During the extraction voltage recovery all kinds of ion masses can pass through the analyzing system, resulting in an implant with a high level of impurity if the beam can reach the wafer. An acceleration glitch results in an implant with incorrect energies. A fast sampling and control loop is needed to properly deal with these interruptions. The E220 detects a beam dropout in less than 2 ms and blanks the beam into a dump location until it recovers.

CONCLUSION

The high cost of 200mm wafers will push dosimetry systems to improve the integrity of the implant, including proper recovery from beam interruptions. Wafer fab production control will require larger amounts of information about each individual wafer to be available. Furthermore device geometries below 0.35μm will require better control over charging, uniformity, repeatability, total dose, implant depth and beam purity, probably on even larger wafer sizes. This will impose even tighter restrictions on the dosimtry systems accuracy.

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