Introduction to Low Pressure Glow Discharges for Semiconductor Manufacturing with special Emphasis on Plasma Etching

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Abstract

Plasma processing is one of the key technologies in the fabrication of modern silicon devices. It is applied to approximately one third of the several hundred fabrication steps. Plasma etching enables together with advanced lithography the high volume production of submicron structures. The significant difference to the formerly used wet etching in liquid chemicals is its ability to keep the mask dimensions much more accurately. Plasma assisted deposition reduces the necessary number of high temperature thermal treatments $> 700°C$ which might degrade the device performance, as it allows the deposition of several important materials in semiconductor manufacturing at below $500°C$. Finally plasma treatments are used to modify surfaces e. g. to increase wetability of chemicals, to clean organic residues and so on.

This short summary on low pressure glow discharges used in IC manufacturing is intended to give an introduction to the basics of the plasma processing involved in the IC fabrication process. It is devoted to the physical and chemical concepts of plasma etching and a bit deposition, but addresses also the overall IC fabrication briefly, because many specific requirements can only be understood in the context of the total fabrication process.

The script is mainly considered for young process engineers and technicians working in the wafer fab, giving them a rather practical introduction, but might be also interesting for all persons who want to get in touch with the subject. While reading, please be always aware that my main intention is to give you some feeling and conceptual knowledge, not detailed recipes for specific applications. I might have omitted expections, doesn't have described all restrictions, so don't take the given arguments to literally and seriously, but anyway the concepts introduced should be valid. Due to the complexity of our subject I try to explain all related terms shortly during the first chapter to have a good basis for the more detailed discussions following. Most of the given examples come from submicron CMOS technology as this is my current field of interest.

Most of the basic material presented comes from four books of Chapmann [1], Liebermann [5], Chen [2] and Sugawara [7]. The first one of Chapmann is already more than twenty years old but is still a excellent first overview. The graduate textbook of Liebermann provides a rather complete coverage together with a rather strict quantitative analysis. Chens book is not devoted to plasma processing, it is about plasmas and controlled fusion and is my reference for questions to basic plasma physics. The final one edited by Sugawara is rather new from 1998 and contains therefore very actual material. I just selected, summarized and expanded everything in a way that is in my humble opinion useful for the actual practical application.

Contents

Chapter 1

Introduction

Some years ago when I started to read and learn about plasma etching the numerous terms used in the literature were rather confusing for me. Therefore I will try to use a consistent nomenclature in the following. Within the first chapter all the important issues (from my limited point of view) will be touched and defined shortly. It starts with a short overview of planar technology used in todays wafer fabs to produce modern ICs. Then a introduction to glow discharges and plasmas is given before the two fields are combined the first time to explain the basics of plasma etching. In the following typically used plasma sources and etching processes are described before the chapter finishes with an introduction to plasma assisted deposition and plasma damage.

1.1 General Aspects of the IC Manufacturing Process

Integrated circuits are fabricated using planar technology on single crystalline semiconducting substrates. The substrate, called a wafer, is shaped as a disc typically 50 - 300mm in diameter and less than 1mm thick. On one wafer from tens to hundreds of individual ICs were fabricated.

Planar technology is based on the deposition or growing of conductive and dielectric layers, transfer of the desired pattern into that layers and doping of parts of substrate with specific impurities. The loop above is repeated continously depending on the complexity of the device. Layers as thin as a few atoms up to a thickness of some micrometer are made. The lateral dimensions created by modern lithography and etching are below 180nm in the most advanced devices in mass production. In typical submicron silicon technology around one third of the several hundred manufacturing steps are based on plasma processing. The subsequent formation of conductive lines for wiring and dielectric layers for vertical isolation, with small openings to connect the different wiring levels, leads to a complicated topography on the device, imposing significant challenges to the structuring process.

Figure 1.1 shows a typical sequence to form an aluminum interconnect layer. First the aluminum is deposited by a sputter process; next the light sensitive photo-resist is coated on the metal by a spin-on process. The photo-resist is

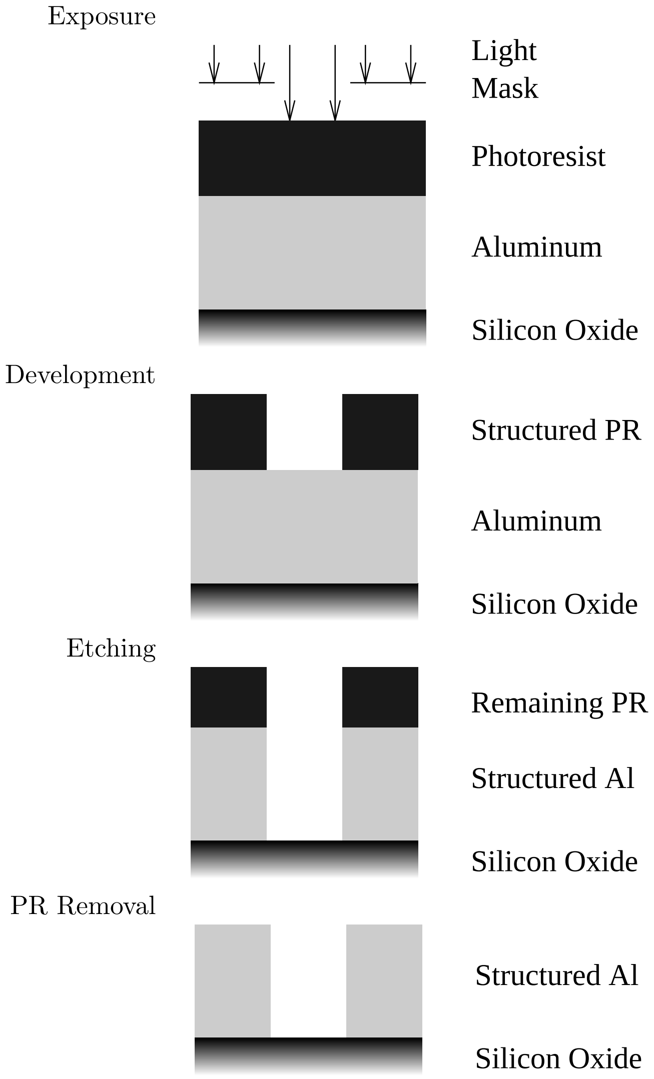

Figure 1.1: pattern transfer

then exposed through a mask with light of a suitable wavelength[1]. This light changes the chemical structure of the resist, making it soluble in a suitable liquid, by a process is called development. The total resist coating, exposure and development sequence is named lithography. After replicating the mask pattern into the resist the transfer to the aluminum by etching takes place. In modern processes plasma etching is applied as it best keeps the sizing of the resist mask which protects the material at the desired locations from being etched. Finally the remaining photo-resist is removed by dissolving it in a liquid or transforming it to volatile species that can be pumped away in a vacuum chamber. The later process is usually done in a plasma assisted environment and called plasma stripping or ashing.

The other main task in semiconductor manufacturing, beside the delineation of designed patterns, is the doping of specific areas on the device. Hereby it is possible to alter the conductivity of silicon by many orders of magnitude and nonlinear effects appear which allow to create electronic devices. Doping is done in a similar manner as the structure formation described above. First the mask that covers the areas which should not be processed is created by lithography. Then a ion beam built of species to be implanted is directed towards the wafer. Depending on the energy of the particles and the exposure time of the wafer to the beam, different depth profiles can be achieved. In silicon technology mainly boron, phosphorus or arsenic is used to form the n and p regions necessary to build field-effect and bipolar transistors.

1.2 Glow Discharges in Inert and Reactive Gases

So far we used the terms plasma and discharge or glow discharge already several times without giving a clear definition. In the following and also in daily live of materials processing the two terms were used synonymously because both were linked to the subject of more or less ionized gases. In the world of physics the terms are handled rather different (indeed a real physicist would not like such a sloppy nomenclature). The concept of plasmas is very general and applied to describe phenomena involving charges from outer space to conducting electrons in metals. A plasma is very homogenous without edge effects, it can be characterized by two parameters, its density n and temperature T. On the other hand, the glow discharges which are the subject of our discussion are rather different. E. g. they have clear boundaries, called sheaths[2] and instead of one temperature, different temperatures for electrons, ions and neutrals may be defined. But before going into details, one thing should be mentioned: Even if typical discharges in materials processing are far away from being an ideal plasma, many concepts developed here can be applied on a qualitative or semi quantitative basis also to glow discharges. The following definition of a plasma is given by Chen [2]:

> *A plasma is a quasi-neutral gas of charged and neutral particles which exhibits collective behavior.*

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[1] in submicron technology as illumination sources nowadays mainly mercury lamps (365nm) and excimer lasers KrF (248nm) or ArF (193nm) are used

[2] the sheaths play a dominant role in materials processing

Before the sentence above is meaningful we have to further define quasi-neutral and collective behaviour, a task which is rather difficult based on the material which we already covered. Therefore we will start by some heurisitic arguments and everything will be covered again later in a greater depth.

Let us consider an arbitrary neutral gas where no macroscopic forces act on the constituents (gravity is negligible), then their motion is controlled just by collisions among them. A macroscopic force like e. g. the compression of the gas is transmitted by those collisions to the individual atoms or molecules. In case of the before mentioned example of compression the number of collisions would increase. This situation changes totally if we allow our particles to carry electrical charges. This moving charges create electric fields, currents and magnetic fields which influence other particles far away. This is meant by *collective behaviour.*

The just given explanation was already rather empiric, but our situation for quasi neutrality is even worse. One important characteristic of plasmas is their capability to shield out electrical potentials applied to them by redistributing their charged constituents. It is possible to calculate a characteristic length, called Debye length λ_d, over which the imposed electric potential decays. With this knowledge we can now define *quasi neutrality* which requires the following conditions to be satisfied:

- The Debye length λ_d must be much smaller than the system dimension L:

$$\lambda_d \ll L.$$

- The Debye shielding is a statistical concept where many charged particles are required to cancel the electrical potential. So the number of particles N_d in a sphere with a radius of λ_d must be sufficiently high:

$$N_d \gg 1.$$

- Finally on macroscopic scales the plasma must be basically neutral, means the number of positive (ions) and negative (electrons) charges must be nearly equal:

$$n_i \simeq n_e \simeq n.$$

After finishing this a bit dry tasting, but very important definitions, we should have a look on the roadmap for the rest of this section. First we will review the ideal gas, especially the relationship between the macroscopic properties and the individual movement of its constituents (kinetic gas theory). Next collisions among the particles in the plasma will be considered as they are substantial for sustaining the plasma via ionization. Then there is a more practical part concerning vacuum technology, before we switch back to the electrical characteristics of plasmas addressing mobility and plasma potential.

1.2.1 Gases and Ideal Gases

The gaseous state of matter is characterized by the fact that it fills always all the available space, means a gas has neither a specific shape nor a defined volume.

Microscopical a gas consists out of individual particles with a specific volume and some distance between. The constituents can interact by elastic and inelasic collisions.

A gas is considered as ideal if it can be described just by the three macroscopic properties temperature, volume and pressure. The following relation must hold between the macroscopic variables of an ideal gas:

$$pV = Nk_BT, \tag{1.1}$$

where k_B is the Boltzmann constant, T the absolute temperature in Kelvin and N denotes the total number of gas molecules/atoms. In materials processing usually the absolute number of particles is not as important as the particle density n:

$$n = \frac{N}{V} = \frac{p}{k_BT}. \tag{1.2}$$

From the previous equation it is obvious that the gas density depends only on pressure and absolute temperature. By filling the above formula with numbers we get:

$$n = 7.243 \times 10^{16}\ \frac{p/Pa}{T/K}\ cm^{-3}, \tag{1.3}$$

$$n = 9.657 \times 10^{15}\ \frac{p/mTorr}{T/K}\ cm^{-3}, \tag{1.4}$$

where pressure and temperature are measured in Pascal and Kelvin, the second formula is the same just with the pressure given in mTorr, as this is still very commonly used, if you are active etching you what I am talking about, one equipment vendor likes Torr or mTorr the other Pascal and you are continously calculating how many mTorr is one Pascal, remember it is 7.5mTorr. To get more in touch with the numbers involved lets calculate the density at a typical processing pressure of $1Pa$ and a temperature of $300K$. The resulting density n is 2.4×10^{14} particles per cubic centimeter. If we reduce the dimensions to the typical feature size in semiconductor manufacturing of $1\mu m$ then a cubic with this width contains just 240 particles.

The term ideal gas relates to the fact that the state does not depend on the kind of gas, all gases behave in the same way. In reality, especially at higher pressure and lower temperature, this is not always true, but under the typical conditions of material processing all gases can be treated as ideal. In the kinetic gas theory eqn. 1.1 can be deduced from basic principles under the following boundary conditions:

- The total volume of the constituents V_c is negligible compared to the volume V in which the gas is enclosed,

  $$V_c \ll V. \tag{1.5}$$

  This means also that most of the space is empty and the distance between the the particles is much bigger than their size.

- The particles interact just by elastic collisions, exchanging kinetic energy among them and with the wall.

From this it is quite clear why especially at low pressure most gases can be treated as ideal. As we saw in eqn. 1.2 lower pressure means lower density. So less particles per volume lead to long distances and small interactions between them. As we will see in the next section on kinetic theory not the type or mass of the constituents is important, just the kinetic energy.

Kinetic Gas Theory

The absolute temperature T corresponds to the average kinetic energy of the particles.

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}k_B T, \tag{1.6}$$

here m is the mass of the particle and v is the velocity. As we can see the higher temperature causes a higher velocity.

On the other hand the pressure is caused by the momentum transfer from the gas components to the wall. This means if more or higher velocity particles impinge on the wall the pressure increases (see fig. 1.2). Therefore the relation that an increase in the gas temperature causes an increased pressure is clear. The higher temperature leads to higher average velocities and hereby more particles (with higher velocities) can reach the wall in a given time so that the momentum transfer is increased and the pressure rises.

Figure 1.2: wall collisions causing pressure

Maxwell-Boltzmann Distribution

The kinetic energy distribution of electrons, ions and neutrals is very important for characterizing a gas. From statistical arguments and also from experiments the so called Maxwell Boltzmann distribution can be derived (see fig. 1.3). This indicates the portion of the gas constituents having a specific velocity v in thermal equilibrium (m denotes the mass of the particles). At www.gs68.de you can plot a Maxwell Boltzmann Distribution online.

$$f(v) = \frac{4}{\sqrt{\pi}} \left(\frac{m}{2k_B T}\right)^{3/2} v^2 \; e^{\frac{-mv^2}{2k_B T}}. \tag{1.7}$$

The shape of the distribution gets wider for higher temperatures and also the peak decreases. It is possible to calculate a mean speed $\overline{v}$ which is equal to:

$$\overline{v} = \int_0^\infty v \; f(v) \mathrm{d}v = \sqrt{\frac{8k_B T}{\pi m}}. \tag{1.8}$$

The mean speed is always higher than the most probable speed due to the skewness of the distribution. For Argon atoms at 20° C (=295K) $\overline{v} = 394$m/s.

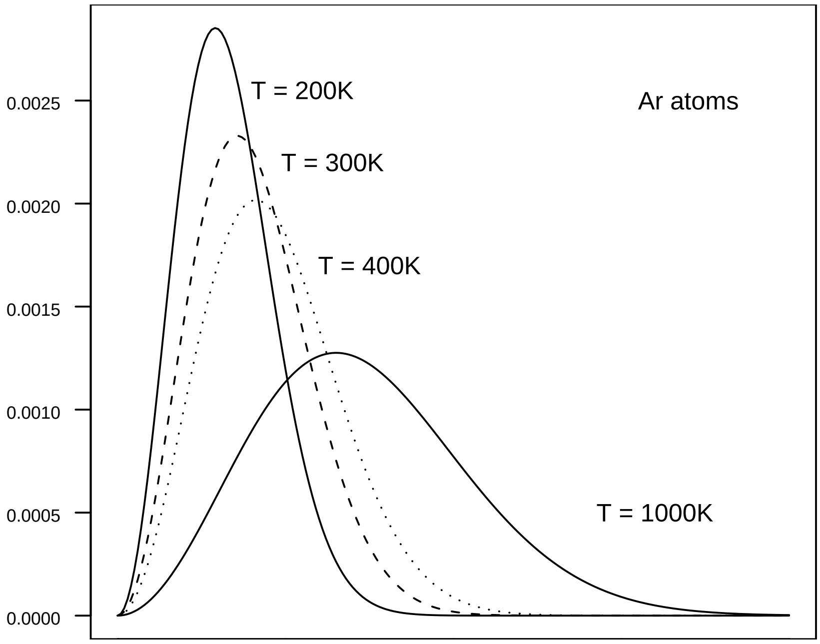

Figure 1.3: Maxwell Boltzmann distribution

Collision Parameters

Collisions among the constituents of the gas are the essential process that drives the gas into thermal equilibrium with particle velocities according the before introduced Maxwell Boltzmann distribution. Many different phenomena are observed when two particle collide. Energy, momentum or charge maybe exchanged between the particles involved, but their sums are conserved. This variety of processes will be covered in more detail in the following section 1.2.2, within this section we will have a closer look onto the typical distance $\lambda_m$traveled between collisions and their occurrence frequency ν.

1.2.2 Atomic and Molecular Collisions

Atoms and molecules have, beside their kinetic energy, internal energy levels by electronic and/or vibrational/rotational states, means they also have potential energy.

1.2.3 Vacuum Technology

1.2.4 Electron and Ion Mobility

The concept of mobility is used in plasma physics, to describe the drift velocity of charged particles under the impact of an electric field E. The significantly different mobility of electrons and ions in weakly ionized plasmas is of crucial importance for the understanding of fundamental issues like plasma potential and self bias voltage in materials processing. Due to this remarkable importance we will go a little deeper in that issue already here.

Let us assume a cloud of electrons subjected to an external electric field E, which will accelerate them in opposite field direction. The electrons cannot continously aquire higher velocity because the collision probability with other particles is also increasing at higher speed. A steady state with some net drift velocity v_d will be established.

This is clear by recalling the following assumptions and facts, that we already partially considered.

- The discharges of our interest are weakly ionized, means the dominant collision partners for charged particles are neutrals, collisions between charged particles must not be considered.

There is an equilibrium where the average drift velocity is proportional to the applied field electric field E:

$$u = \mu E. \tag{1.9}$$

The proportional constant μ is called mobility.

Nearly the complete power is transfered to the electrons due to the significant mass difference $m_e \ll m_i$, m_e denotes the electron and m_i the ion mass respectively. For illustration we will follow a simple argument given by Chapmann [1]. Consider the example of a constant electric field E acting on an initially stationary single charged particle. After a given time t the particle traveled the distance x, where the acceleration a depends on the magnitude of the field

$$x = \frac{1}{2}at^2 \quad \text{with} \quad a = \frac{eE}{m}.$$

Therefore the work done on the particle is given by

$$W = eEx = \frac{(eEt)^2}{2m}.$$

As we can see the mass turns up in the denominator, resulting in a much higher energy transfer from the electric field to the light electrons compared to the ions, as stated above.

1.3 Basic Concepts and Terminology in Plasma Etching

In my personal opinion, learning about such a rather complex system with many interactions as plasma processing is not 100% straight forward. It's more like solving a self consistent equation system by starting with a rough estimate and refining it step by step. Means you need to know something about all single concepts, like electrical discharge parameters, gas flow dynamics, surface chemistry and so on before you can get a better understanding of the interactions among them. But without knowing the links you cannot get a deeper knowledge of the single topics in relation to plasma processing. I am now several years in this business and the loop seems to continue forever on.

The most fundamental term in this context is "plasma etching" itself, it denotes the continues removal of material from a surface by physical and/or

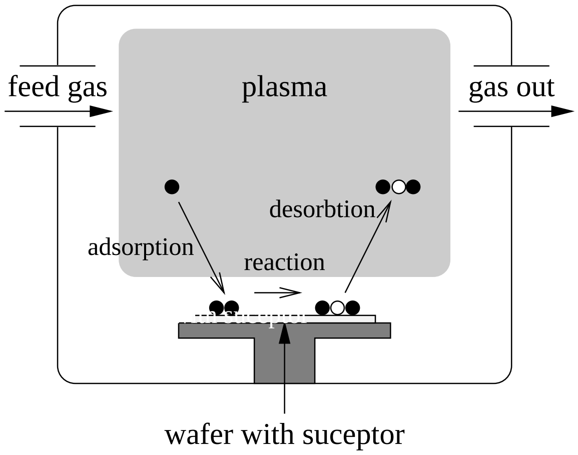

Figure 1.4: schematic view of the etching process

chemical processes. Etching in a discharge environment is achieved by providing active species, which react with the substrate forming volatile products. In plasma etching the reactive species are ions and activated neutrals, created in an electrical discharge. The process takes usually place inside an reactor under well controlled environmental parameters like e. g. pressure, temperature and feed gas flow. In more detail, the etching process can be divided into four steps (see also fig. 1.4):

Formation of active gas species. The source gas mixture is feed to the discharge chamber, where it is partially converted to ions and reactive neutrals.

Transport of the active species to the surface. The active species are created in the bulk plasma or ion sheats, from where they are transported mainly by diffusion, to the substrate surface. Charged particles are also influenced by drift motions due to electric and/or magnetic fields.

Reaction at the surface. This step it can be further split into three substeps, namely the adsorption of the precursors, the surface reaction and desorption of the products. Especially for the reaction sub-step a wide variety of mechanisms exists. For example, processes that depends mainly on the energy of the impinging ions are said to have a big physical component. The opposite is a chemical etch, where mainly activated neutrals react with the substrate independent of their kinetic energy. In practice most processes have both physical and chemical aspects.

Pump down of the reaction products. After the desorption the volatile reaction products diffuse back to the bulk plasma. Here they exhausted by a vacuum pump. The different diffusion directions of etchants and reactions products are caused by the locations of the maximum concentration of both species, which are the bulk plasma and substrate surface, respectively.

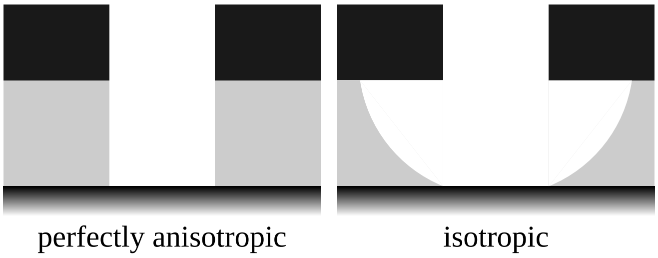

Figure 1.5: profile evolution

isotropic/anisotropic/notching/trenching,residues loading/microloading/arde mechanisms to achieve defined profiles/defined particle beam IBE, RIBE / sidewall passivation/ low temperature processing combination of physical/chemical aspects different nature Al/Cl SiO/CF

1.4 Interactions between Plasma, Substrate and Etching Equipment

1.5 Commonly used Plasma Sources

In the previous sections 1.2 and 1.4 we discussed already that the glow discharge is loosing continously energy when electrons and ions escape to the wall. On the other hand we defined in the same sections the plasma to be in a steady state, means a mechanism that feeds energy back to the plasma must exist. In all discharges relevant to semiconductor manufacturing the balance is achieved by coupling electromagnetic power to the plasma. Hereby the few always existing electrons are accelerated until they aquire enough kinetic energy to create new electron/ion pairs by inelastic collisions with neutral atoms or molecules. Nearly all energy is transfered to the electrons, due to their significant higher mobility which was already discussed in section 1.2.4.

The term plasma source denotes the mechanism and/or apparatus that transforms the supplied electromagnetic energy into acceleration of electrons. This kinetic energy sustains the plasma by electron impact ionization. Actually, in discharges relevant to semiconductor manufacturing there are four basic mechanisms/apparatus applied. Three of them will be discussed briefly in the following sections, namely capacitive, inductive and wave heated discharges. Chapman [1] gives a good introduction to capacitive discharges, the graduate level book of Lieberman and Lichtenberg [5] as well as Popov [6] address all three kind of sources mentioned above.

The fourth, the DC discharge is historically important, but actually due to the necessity of driving a constant current through the sheaths not applicable for plasma etching/deposition of insulators. Instead is is used for the sputtering of conductive materials like aluminum, tungsten or titan. As my personal knowledge (and interest?) is not so big for sputtering processes, I'd like to point you for a more thorough understanding to the literature, the books of Chapman [1] as well as Franz [3] provide a good introduction and further references.

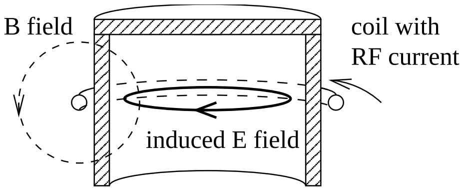

Figure 1.6: principle of ICP

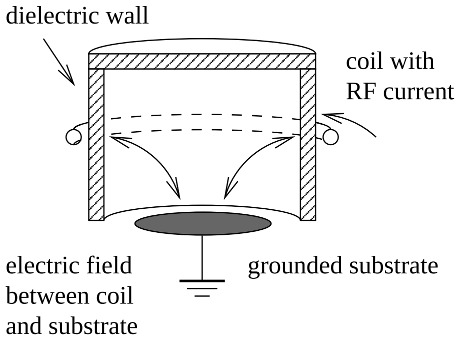

Figure 1.7: capacitive coupling in the ICP

1.5.1 Capacitive Discharges

1.5.2 Inductive Discharges

wavelength in icp is 30m

1.5.3 Wave Heated Discharges

1.6 Typical Etch Processes in Submicron CMOS Technology

Within this section some of the typical applications of plasma etching in modern CMOS processes will be discussed. The material should give some basic understanding for the specific issues of the different applications like gate etch or contact etch. Hereby you should never forget that etching is just a part (even an important one) of the total manufacturing process and the final goal is to integrate all processes to yield good wafers.

1.6.1 Photo Resist Stripping

Photo resist stripping or also call ashing is one of the first applications of plasma treatments in semiconductor manufacturing. It came up in the 1970s using pure oxygen plasma to oxidize the organic resist and react it to gasenous CO_2 and H_2O, which can be pumped off in the vaccum system. Since that time etching and ion implantation have changed quite a lot to fulfill the requirements of the continous shrinking device dimensions. Removing the resist after a high dose ion implant or after a modern via etch is a really difficult task now. In the following we will briefly discuss some basics of resist removal, covering principles, chemistries and special applications.

Basic Processes

For our discussion we will treat the photoresist usually as a polymer consisting of carbon (C) and hydrogen (H), the other species present in resist are of so low concentration that they can be ignored (maybe not always for contamination issues, but for the topic here). In plasma assisted resist removal there are to basic reaction ways to form volatile reaction products:

Oxidation: here the resist polymer is oxidized, the basic reaction is:

$$\mathrm{C_xH_y + O_2 \ \rightarrow \ CO_2 + H_2O}.$$

Reduction: here the resist polymer is reduced by H_2, the basic reaction is:

$$\mathrm{C_xH_y + H_2 \ \rightarrow \ CH_4},$$

more commonly used is NH_3:

$$\mathrm{C_xH_y + NH_3 \ \rightarrow \ HCN + CH_4} + \text{others}.$$

Today in nearly all ashing processes oxygen in one or the other form (O_2, Ozone O_3, H_2O) is used to oxidize the resist and transfere it to gasenous species which are pumped away. Reducing chemistries were proposed time by time, but they are not widespread in mass production because of safety concerns. Technically they would be interesting because some materials redeposited from the etching process like Ti form nonvolatile oxides that could be avoided by reducing chemistries. The rest of the section will deal, due to the importance of the oxidizing processes, primarily with those.

Requirements

There are several different requirements for a practical ashing process.

- The cost of the stripping process needs to be low cost per wafer, calling for cheap and simple equipments as well as high throughput. To achieve resonable wafers per hour the ashing rate should be higher than $1-2\mu$m/min for single wafer tools, barrel (batch) type equipments can be slower, depending on the batch size.
- To remove the resist without leaving residues or contamination is the key requirement for the ashing process. Residue free stripping of an untreated resist is usually no problem, much more difficult are the polymers (see page 16) or crust (see page 16) formed by etching or high dose/energy implantation.
- The ashing process must be gate oxide damage free (see section 1.8). Also other potential damages like low-k dielectric degradation need to be considered when relevant.

High Temperature Oxygen Process

The most simply process uses pure O_2 in a downstream plasma reactor. In this case the wafer temperature is of siginficant importance, as the process must be additionally thermally activated. To get some reasonable ashing rates ($> 2\mu m/min$) for single wafer treatment temperatures of at least 130-170°C are required. The same process is carried out also in barrel reactors using lower temperatures. Throughput increases linear with temperature, but above appr. 250-300$°C$ the resist starts to burn (reticulate), practically limiting temperatue. A huge benefit of the pure O_2 process is its nearly infinite selectivity to Si, SiO_2, Al and other important materials used in semiconductor manufacturing. But there is one important exception, low-k materials. Here problems with k value changes or side wall bowing might happen.

For the above mentioned process some nitrogen addition can increase the ashing rate. This is sometimes attributed to the fact that the lifetime of the oxygen radicals is increased when nitrogen is present in the discharge.

Low Temperature Process with Flourine Addition

An alternative for the pure high temperature O_2 process is a O_2/CF_4 chemistry. This process can be carried out also at room temperature because the F radicales remove H from the resist, leaving open bonds that can be attacked even by room temperature by oxygen. There is the additional advantage that also some inorganic residues can be removed by the flourine radicals for the price of slightly reduced selelectivity to Si as well as SiO2.

Additional species can be added to the process above for dedicated purposes e. g. to enhance selectivity, improve residue removal (or make them at least water soluble) so used chemistries could consist of: O_2, CF_4, CHF_3, CH_2F_2, N_2/H_2, NH_3, H_20.

Low k Material Ashing

This is actually [3] a quite hot topic in semiconductor manufacturing. Here it depends on the material, FSG (flourinated silicon glass) can be treated nearly as standard, but if we move to lower k films the situation changes quite dramatically. The main concerns are: change of k value (e. g. by oxidizing the film in an O_2 plasma), sidewall bowing (the film might be etched at the side walls) or chargeup RIE damage.

Actually it seems that most resist removal on low k material is not done on ashing equipment but on etching machines. The key point to avoid the damage mentioned above seems to be, to separate ion density and energy by using an ion source and add some bias. Means e. g. an ICP or Microwave source and place the wafer on a stage with RF bias. This processes operate under low pressure and low temperature and use same chemistries as mentioned above. There are also reports that O_2 alone works.

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[3] As this writing is a long project actually means 2004

1.7 Basic Concepts of Plasma assisted Deposition

1.8 Plasma Damage

When we talk about plasma damage, various issues can be considered, e. g. damage to the silicon crystal during LDD spacer formation or contact etch resulting in junction leakage and/or high contact resistance. In modern low-k interconnect schemas, e. g. plasma ashing by oxygen can increase the k value of the low k material, rendering its costly application useless. But in most cases if we talk about plasma damage we think of degradation of devices like transistors or memory cells by non uniform charging and/or UV radiation during plasma processing. These two effects can cause significant current transport through the gate oxide, changing its electrical characteristic. Therefore gate oxide breakdown and wear-out mechanisms will be reviewed, as a prerequisite, very briefly.

1.8.1 Gate Oxide Breakdown and Wear-Out

1.8.2 Plasma Non-Uniformity

1.8.3 Topography related Effects

1.8.4 UV Radiation

1.8.5 Damage Measurements

Chapter 2

Glossary

Crust. During high dose implantation using photo-resist masks, the implanted species (especially heavy ones like arsine) transfere the upper layer of the resist to pure carbon by knocking out hydrogen, this is lyer is called crust. During subsequent heat treatments (e. g. the stripping process) remaining solvent in the resist below the crust might expand and cause explosions that form particles. This phenomena is usually called popping.

Etching Rate. The amount of material removed per unit time in an arbitrary direction from the surface, given e. g. in nm/s or μm/min. Depending on the etching process the etching rate in horizontal and vertical

Interconnect.

Lithography.

Mask. Mask

Pattern Transfer. During the fabrication of an typical IC several different layers with different structures must be created to form the entire IC 1.1.

Photo-resist (PR). A organic material which is typically coated onto the surface by a spin on process. The photo-resist changes its chemical properties by exposure to light of a suitable wavelength. Depending on the material the exposed or non-exposed parts can be wet etched or developed by an appropriate solution.

Polymer. A rather poorly defined term, very widely used in plasma etching to denote something not perfectly known, deposited from the plasma to protect sidewalls, achieve high selectivity or to the other side, form films on the chamber creating particles. In general a polymer is a chain formed from smaller molecules, in plasma etching polymers consist mainly from some coumpounds out of the following list: carbon (from the resist mask), flourine, hydrogen, metals (redeposited from the etch process). But also Si-O-Cl or Si-Br-O compounds deposited for sidewall passivation in poly etching are called polymers. Polymers are usually difficult to remove and are a real challange for the stripping process.

Selectivity. The ratio of the etch rates of different materials under the same process conditions. In practice this is an important issue, consider e. g. an insulating layer of silicon oxide over silicon which should be etched through without damaging or removing the substrate.

Sputtering. Removal of material ..

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Index