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Approaches for patterning of aluminum

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Abstract

In semiconductor technology, aluminum is the preferred metallization. Sophisticated structures use a sandwich layer consisting of a Ti/TiN or TiW barrier layer, the aluminum itself, and Ti/(TiN) on top (ARC, electromigration enhancement, adhesion layer). For the patterning of these sandwiches, dry etching (RIE – Reactive Ion Etching) methods based on chlorine and bromine chemistries are commonly used. Etching tools are standard parallel-plate reactors, Hexode-systems, MERIE-systems, and, recently, inductive-coupled plasma sources. In this paper the different chemistries including the new aluminum/iodine system are discussed, as well as the different etching equipment. New approaches try to substitute RIE by chemical mechanical polishing (CMP), also called ‘Damascene’. In this process sequence, the isolation oxide is deposited first, and the aluminum structure is etched into the oxide by RIE methods using a photoresist mask. After oxide etching and resist removal, the aluminum is filled in the structures and the residual aluminum is polished away by CMP. Finally, a second isolation layer is deposited. This paper will analyze this new approach and will compare it to the existing RIE methods.

1. Introduction

In semiconductor technology, metal layers are used for wiring the active areas within the chip. For advanced metallization schemes [1,2], sandwiches containing aluminum, aluminum alloys, Ti, TiN or TiW are employed. The aluminum layer is used as the conductor itself, while Ti, TiN and TiW form a barrier layer to avoid interdiffusion of aluminum and silicon (‘spiking’). The aluminum is often alloyed with copper and/or silicon to enhance the electromigration resistance.

At the beginning of LSI technology, wet chemical processes were used for patterning of aluminum. Since these processes show an isotropic etch profile, wet chemical processes were soon replaced by plasma-assisted anisotropic RIE processes (Reactive Ion Etching). The aluminum layer is first covered partially with a photoresist mask. In the subsequent dry-etch step, the aluminum is removed within the uncovered regions by reactive ions and radicals generated in a plasma above the wafer. An aluminum RIE process [3–11] can be separated into three steps. In the breakthrough step, the native Al_2O_3 layer as well as the remaining humidity (‘scavenging’) are removed. After this etch initialization, the metal layer itself is removed in the main etch step. In the overetch step, the remaining metal especially in clefts is eliminated.

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New approaches try to substitute RIE by chemical mechanical polishing (CMP), also called 'Damascene' [12–14]. In this process sequence, the isolation oxide is deposited first, and the aluminum structure is etched into the oxide by RIE methods using a photoresist mask. After oxide etching and resist removal, the aluminum is filled into the structures. Subsequent to the aluminum fill, the residual aluminum on the areas where no structures should remain is polished away by CMP and a second isolation layer is deposited. With the Damascene sequence, typical RIE problems, such as a lack of photoresist selectivity, insufficient profile control and corrosion can be avoided. On the other hand, problems with oxide etching, the filling of narrow structures with aluminum and with the polish of the 'soft' aluminum occur.

2. RIE processes

2.1. Etchants

Important for a successful aluminum RIE technology are the reactor technology and the etching chemistry. As etchants, mainly halogen-containing gases are used. Fig. 1 shows the enthalpy of formation (EOF) and Fig. 2 shows the vapor pressure of the etching products for the different halogens: fluorine, chlorine, bromine and iodine. It should be mentioned that contrary to the patterning of silicon layers, SiO_2 layers and Si_3N_4 layers, fluorine-containing etchants cannot be used for

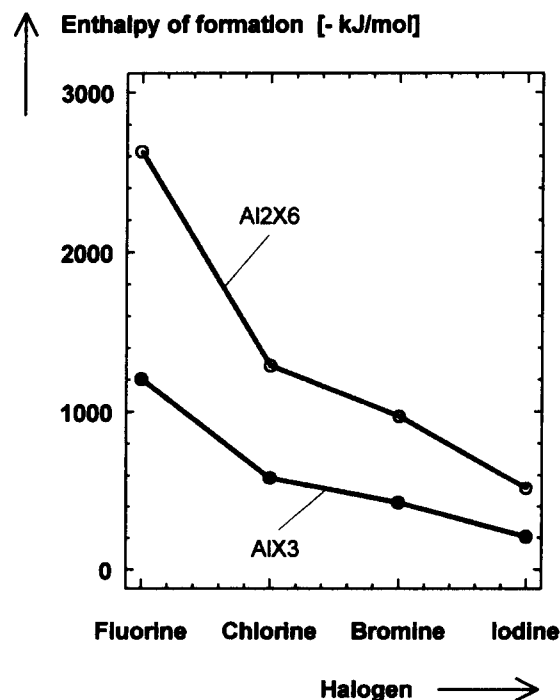


Fig. 1. Enthalpy of formation (EOF) of the aluminum halides AlX_3 and Al_2X_6 (dimere shape).

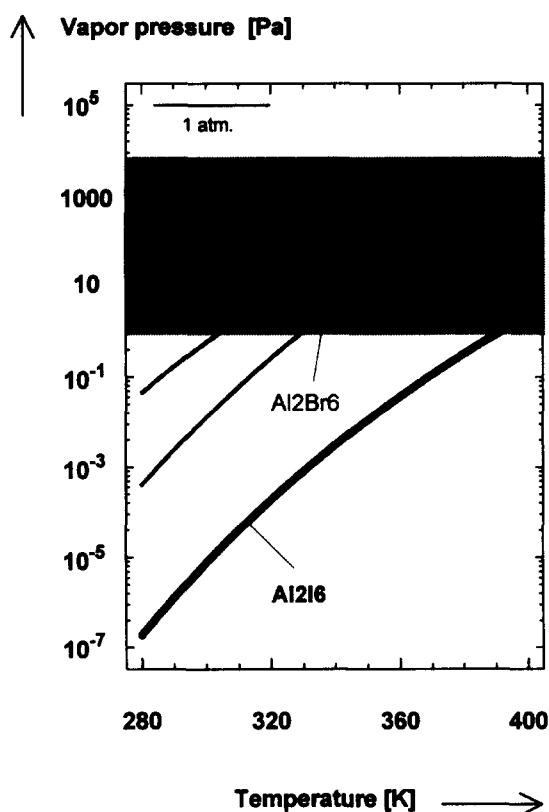


Fig. 2. Vapor pressure of the aluminum halides Al_2X_6 .

aluminum etching. This is due to the insufficient vapor pressure of the etching product, aluminum fluoride (AlF_3), which remains on the etched surface and leads to an etch stop.

2.1.1. Chlorine-based chemistry

The first RIE processes used chlorine-containing chemistry based especially on carbon tetrachloride (CCl_4) [15–23]. Following aluminum fluoride, aluminum chloride shows the biggest EOF (Fig. 1) which indicates an aggressive attack of the aluminum. The reaction of aluminum with chlorine itself is self sustaining. The etchant CCl_4 shows a good breakthrough capability, polymerizes easily in the plasma and forms a sidewall film required for anisotropic etching (protection against spontaneously reacting chlorine radicals). An intense polymer formation, on the other hand, leads to corrosion problems (remaining chlorine in the sidewall film) and to an inaccurate profile control (CD variations depending on the thickness of the sidewall film). Furthermore, the etch chamber and the wafer will be contaminated by the polymers.

Next-generation approaches tried to control the strong polymer formation by the use of a mixture of CCl_4 and chlorine [24–27]. With this mixture, the etch rate can be enhanced and the problems connected with the intense polymer formation can be improved but not completely solved. Since dissociation products of CCl_4 like C_2Cl_2 are also very carcinogenic and environmental protection

issues (CFC problem) are gaining more and more importance, CCl_4 is no longer used for aluminum etching today.

As an alternative, the chlorine-containing carbon-free etchants BCl_3 [28,29] and SiCl_4 [30–34] are proposed. BCl_3 shows the best breakthrough capability of chlorine-based etchants, and is, therefore, used in nearly all breakthrough steps in modern processes. In the main etch step it is used to form the sidewall passivation by boron or boron compounds (boron carbide, boron oxide). An etch with straight BCl_3 is difficult because of a low degree of dissociation in the plasma resulting in a low etch rate. BCl_3 is, therefore, used always in a mixture with other chlorine etchants like Cl_2 or SiCl_4 . An interesting property of BCl_3 is the emission of UV radiation within the plasma which leads to a kind of in-situ photoresist hardening (improvement of the temperature stability of the photoresist). BCl_3 is highly corrosive and shows a very small vapor pressure; the handling is difficult. BCl_3 tends to generate particles and is, therefore, critical in terms of defects. Because of these drawbacks, a substitution of BCl_3 would be beneficial. Unfortunately, there are no applicable alternatives with the same breakthrough capability.

SiCl_4 is a modern etchant with benefits in a better photoresist selectivity. The breakthrough capability is lower compared to BCl_3 and CCl_4 . SiCl_4 forms no polymers in the plasma and is, therefore, promising in terms of defect density and contamination. Nevertheless, a sidewall passivation can be formed by silicon or silicon oxide generated by the reaction with moisture or residual oxygen, and silicon carbide (reaction with photoresist). Furthermore, silicon carbide generated by the reaction of silicon with carbon can benefit sidewall passivation. Due to its low etch rate as a single etchant, SiCl_4 is commonly used in a mixture with chlorine and/or BCl_3 [35].

Like SiCl_4 , HCl is a modern etchant. Only few data can be found in the literature. However, recent results of HCl/Cl_2 experiments on deep submicron structures show very promising results [36].

The application of straight chlorine [37–40] is difficult because of the tendency for undercut or isotropic etching (exothermic and self-sustaining reaction of chlorine with aluminum). On the other hand, chlorine processes show a high etch rate and a low contamination level. Chlorine is not carcinogenic, is not a CFC, and it is, therefore, a suitable etchant. In recent approaches at low pressure in new equipment, pure chlorine chemistry is used. At low pressure the directionality of the impinging ions is very high so that only a very thin sidewall film from the photoresist mask is necessary. Due to this very thin sidewall passivation, the CD-control is very good. Nevertheless, the tendency for undercut or notching is very high.

Today, mixtures of chlorine and BCl_3 [41–45] are state-of-the-art for aluminum etching. BCl_3 is used to remove the native Al_2O_3 layer in the breakthrough step and to form the sidewall passivation in the main etch. Since both gases are carbon free, the formation of polymers can only happen if an adequate amount of photoresist is removed during the process. Compared to CCl_4 these processes show advantages in CD control, strippability of polymers, contamination and defect density. On the other hand, a weak polymer generation can cause problems with an unstable sidewall film (very accurate process control to avoid undercut). For an improvement of the process stability, additional etchants can be added to the process gas mixture. One way is the addition of SiCl_4 (no problems with intense polymer formation but sometimes too little sidewall passivation). For some applications, the use of carbon-containing etchants is inevitable to obtain the required anisotropic profile. The use of CCl_4 [46,47] is not appropriate in terms of environmental protection aspects. The addition of CHCl_3 or CHF_3 [48–50] which have quite similar properties to CCl_4 showed comparable or slightly stronger polymer formation compared to CCl_4 and had to be controlled very carefully. CHF_3 is, furthermore, a

fluorine-containing gas. The etch may stop under certain conditions when too much AlF_3 is formed. In terms of environmental protection aspects, the best way is the addition of methane (CH_4) [51]. Compared to CHCl_3 , CH_4 forms less polymers and is halogen free. The incorporation of, for example, chlorine in the sidewall film is, therefore, not so pronounced, which results in a higher corrosion resistance. A good overview over fluorocarbon additions was written by J.-S. Maa [52].

All the above-mentioned chlorine-based approaches show some fundamental drawbacks. One key problem is the lack of photoresist selectivity in a range of not more than 2.5. This results often in problems with the patterning of metal layers over topography. For the complete removal of the metal, especially in deep clefts, a long overetch is required. Processes with a long overetch tend to cause facetting or will lead to a partial etch of the aluminum line when the whole photoresist is removed. In the worst case the line will be completely opened (interruption).

A second problem resulting from the lack of photoresist selectivity is an insufficient depth of focus in lithography. The depth of focus and, thus, the thickness of the photoresist to be exposed decreases with shrinking geometries. To compensate this effect a thinner photoresist mask has to be applied. This can only be realized when the photoresist selectivity is enhanced. If a standard photoresist thickness is used, photoresist residues remain on not completely resolved areas, especially in deep clefts. Furthermore, the aspect ratio becomes very high at very small structures with a standard resist thickness. This can cause a stringent RIE lag (different etch rates and profiles in dense and isolated lines).

2.1.2. Bromine-based chemistry

New approaches propose bromine-based mixtures [53–57]. Aluminum bromide has only a slightly lower EOF (Fig. 1) which indicates an aggressive attack of aluminum comparable with chlorine. The vapor pressure (Fig. 2) of aluminum bromide is lower compared to the aluminum/chlorine system, but still high enough for a sufficient desorption of the etching products. It is, furthermore, known from plasma etching of polysilicon that the photoresist selectivity is enhanced by skipping to bromine-based etchants.

Suitable bromine etchants are Br_2 [53], HBr [54] and BBr_3 [55], whereas BBr_3 has to be considered as rather exotic. It is used with the intention to substitute BCl_3 , but, unfortunately, the breakthrough capability is worse. Since molecular bromine shows an insufficient vapor pressure at room temperature, the gas bottle and the gas lines have to be heated or a bubbler has to be used. HBr shows sufficient vapor pressure and is, therefore, the most promising alternative of the bromine-based etchants.

The photoresist selectivity can be enhanced up to four by the use of HBr -based processes. However, in terms of profile control and CD variations, HBr processes show no distinct benefits. An explanation may be that atomic bromine reacts nearly as aggressively with aluminum as atomic chlorine. Bromine-based processes show, furthermore, problems with silicon and copper residues which remain under certain conditions on the wafer. Residue formation is not so stringent using a mixture of HBr and a chlorine-containing etchant (e.g. HBr/Cl_2) [58,59]. Unfortunately, the photoresist selectivity is lower in this case, but is still higher compared to chlorine-based processes.

The results of chlorine-based processes can be improved by the use of bromine-based processes but do not always meet the requirements. To be fair, it should be mentioned that bromine chemistry is a relatively ‘young’ chemistry and, therefore, much less know-how exists compared to chlorine processes.

2.1.3. Iodine-based chemistry

The aluminum–iodine etch system was introduced very recently [60,61]. The approach is based on the intention of improving profile control by an etchant reacting less aggressively with aluminum than chlorine and bromine. It can be seen clearly in Fig. 1 that the EOF of the aluminum–iodine system is minimal in the group of the aluminum halides. Besides the EOF, the vapor pressure of the etching product is relevant for profile control (Fig. 2). A small vapor pressure can benefit sidewall passivation by the formation of a sidewall film consisting of the etch product. On the other hand, the etching product cannot be removed from the surface when the vapor pressure is too small, and the etch stops. Fig. 2 shows that the vapor pressure of Al_2I_6 is widely below the pressure range used for plasma etching. Considering that ion bombardment enhances the desorption of the etching product, the vapor pressure of Al_2I_6 is in the desired range which enables etching but is low enough to benefit sidewall passivation.

In the aluminum–iodine system, only HI can be used as an etchant (vapor pressure at room temperature is 6.2 bar). All other iodine compounds show a vapor pressure less than 0.5 bar which means that they cannot be handled in a standard gas line. Introducing experiments on a LAM TCP 9600 system with straight HI chemistry and mixtures of HI and BCl_3 , Cl_2 and N_2 show a very good profile control and a very high photoresist selectivity. The profile can be adjusted in a very wide range (Fig. 3) only by a bottom power variation. The photoresist selectivity corresponds with the profiles (more taper results in lower PR selectivity). In a reasonable profile range ($> 80^\circ$), the photoresist selectivity is always larger than 5. It should be noted that comparable chlorine processes show a PR selectivity of no more than 2.5!

The process depends strongly on temperature and HI flow. The etch rate increases nearly linearly with increasing HI flow and temperature. The profile becomes linearly more tapered by going down in temperature. Straight anisotropic profiles of 90° can be obtained at 80°C .

Another important feature is the very high selectivity to TiN/Ti (> 10) as shown in Fig. 4 (no TiN on top). This opens the way to a new process sequence. Main etch and overetch, especially on wafers with severe topography, can be performed with minimum PR loss and with etch stop on the barrier layer. After complete aluminum removal, a subsequent barrier etch step based on fluorine chemistry can be performed. Since aluminum can not be etched with fluorine, PR selectivity is no longer an important parameter.

A BCl_3 addition shows three major effects. The aluminum etch rate and the photoresist selectivity

P_{Bottom}	Profile	PR-Sel.
$< 50 \text{ W}$	isotropic 	> 100
$50 - 75 \text{ W}$	undercut 	$15 - 30$
$> 75 \text{ W}$	90° - taper 	$5 - 15$
$> 250 \text{ W}$	$< 75^\circ$ 	$3 - 5$

Fig. 3. Effect of bottom-power variation.



Fig. 4. Typical etch with straight HI.

decrease distinctively, and the breakthrough time drops from 48 s to 3 s. HI/ BCl_3 mixtures with a HI/ BCl_3 ratio of less than 0.5 are, therefore, very suitable for a breakthrough step. For the main etch step, in contrast to a conventional Cl_2/BCl_3 approach, a BCl_3 addition does not seem to have much potential.

Chlorine addition to HI shows two major responses. With increasing Cl_2 flow the photoresist selectivity as well as the selectivity to TiN drops. In a range of 30 to 60% Cl_2 a PR selectivity of 3–7 and a TiN selectivity of 3–7 (depending upon the other parameters) can be achieved. Since Cl_2 addition seems to be beneficial for a residue-free etch, HI/ Cl_2 mixtures are very promising for a new aluminum etch process (Fig. 5). With this chemistry, the barrier layer can be removed too, if no fluorine-containing gas is available or a fluorine step is not appropriate.

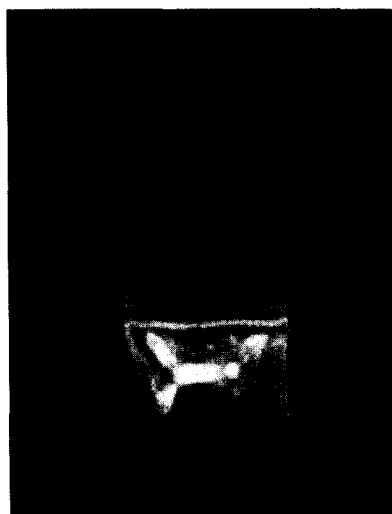


Fig. 5. TiN/Al-Si-Cu/TiN/Ti stack, etched with the new HI/ Cl_2 process.

With significant nitrogen addition to HI, the aluminum etch rate decreases rapidly, while the photoresist etch rate increases. This results in a dramatic drop in PR selectivity. HI/N₂ mixtures with more than 10% nitrogen are, therefore, not suitable for plasma etching of aluminum. On the other hand, some isolated results with small N₂ amounts ($\leq 5\%$) show an extremely high PR selectivity of more than 20 with nice profiles and a sufficient etch rate of more than 400 nm [62].

2.1.4. Exotic approaches

Aluminum can not only be etched with halogen chemistry. It is also possible to apply pseudo halogen systems or an organic approach. A fundamental property has to be that the new etchant shows a sufficient vapor pressure and forms a volatile etch product with the layer to be removed.

Pseudo halogens are defined as compounds, which are equal to the halogens in their chemical behaviour but do not consist of the halogen group VII in the periodic system of elements (F, Cl, Br, I, At). The most important representatives are dicyan (CN)₂ and dirhodan (SCN)₂. Not only the pseudo halogen molecule itself can be used for plasma etching, but also compounds with one or more pseudo halogen groups are possible. From the group of cyanids this would be C(CN)₄, HCN, BCN, Si(CN)₄ etc. For the thiocyanate compounds, the CN group has to be replaced by an SCN group. In addition to the cyanides and the thiocyanates, cyanates can be used. In a cyanate compound the SCN group of the thiocyanate is replaced by an OCN group. Another possibility would be azide-based systems (N₃ group).

For these compounds, no data concerning plasma etching are available. According to halogen systems, hydrogen/pseudo halogen compounds seem most promising. Unfortunately, HCN (prussic acid) is extremely toxic and can only be used with very high safety precautions. HSCN is less toxic but a more stringent acid. Because of the toxic behaviour, these etchants should only be used if there is no alternative system. Azide compounds are very unstable and decompose easily or explode with just a little percussion. An ingenious use of these compounds is, therefore, questionable.

An organic approach is based on organic etchants. In the literature, some approaches concerning the etching of copper can be found. For aluminum etching, only the aluminum/carbon monoxide system is known. CO reacts with a metal to form carbonyls which are mainly volatile in their single-core modification. Since Al(CO)₆ is volatile, patterning of aluminum with CO seems possible. A limiting factor may be the fact that aluminum carbonyl can only be formed under certain defined process conditions resulting in a small process window. A second drawback may be a strong contamination of the pumps.

2.2. Reactor types (equipment)

Besides the etching chemistry, the reactor technology is very important for a successful aluminum RIE patterning process. The standard tool for plasma etching is a parallel-plate reactor (diode system, Fig. 6). The plasma consisting of gas molecules from the etchant, positive and negative ions, radicals and electrons is generated by a capacitively coupled RF power source with a frequency between 100 kHz and 13.56 MHz. The etch reaction onto the wafer is initiated by impinging ions extracted from the plasma. At lower frequencies, ions of both polarities can reach the substrate surface while at higher frequencies only positive ions impinge (different atomic weight leads to a different movement path within one half cycle of the period) resulting in a negative charge on the wafer electrode called

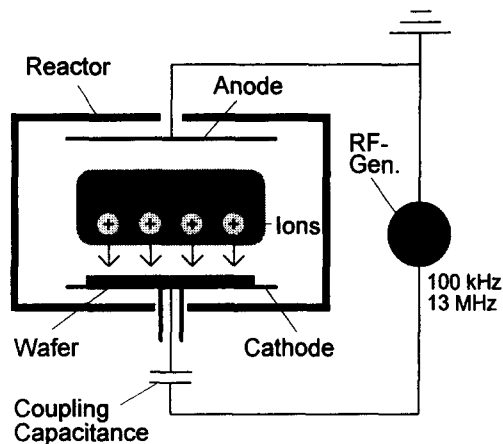


Fig. 6. Schematics of a standard RIE reactor.

'bias'. The bias itself is influenced mainly by the power and the pressure and cannot be controlled independently.

Typical diode etchers are the LAM Autoetch or LAM Rainbow. Both systems are based on the same basic approach but feature a different stage of evolution. A different kind of a parallel-plate reactor is the Hexode system from Applied Materials (or from Plasma Therm, but this company has been shut down), as shown in Fig. 7. The major difference is that a standard diode is designed for one wafer (single wafer system) while the Hex is designed for up to 24 wafers (batch system) depending on the wafer size.

One of the key problems of diode systems is that the ion energy (bias) cannot be controlled independently. To overcome this drawback, a triode configuration can be used. In this approach a second pair of (side) electrodes have been placed within the reactor. The plasma is generated by an RF power source (mainly 13.56 MHz) applied to the side electrodes; the ions for etch ignition are extracted from the plasma with a second RF power source applied to the top and bottom electrode. In this configuration the plasma density can be maintained by the power on the side electrodes and the ion energy by the power on the vertical electrodes.

Another drawback of these systems is that relatively high pressure has to be applied to maintain a stable discharge and to obtain sufficient etch rates. At higher pressure scattering effects are more

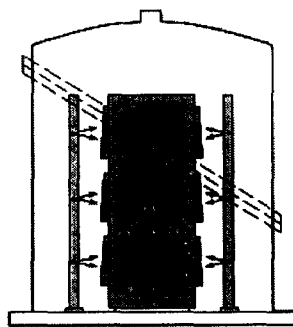


Fig. 7. Schematics of the Hexode system.

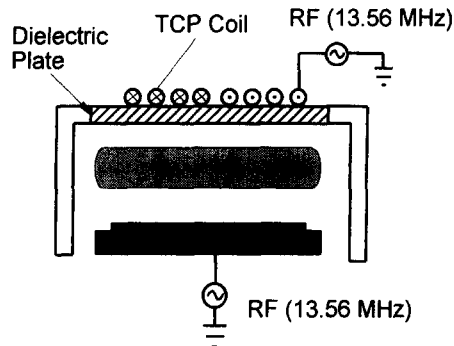


Fig. 8. Schematics of a reactor with inductively coupled plasma (LAM TCP).

severe which require a strong sidewall passivation to ensure the required anisotropy. This leads to problems with contamination, shorter cleaning cycles, particles, profile control, strippability of polymers and distinct microloading effects (different etch rates and profiles in dense and isolated structures). To enhance the ion density, MERIE systems (Magnetically Enhanced RIE) with permanent or electrical magnets can be used. A typical MERIE system is the Applied Materials P-5000. The P-5000 is a single wafer cluster tool with up to four process chambers. One of the process chambers can be an integrated microwave stripper which reduces cycle times and enhances the corrosion resistance.

Today, equipment engineering is focused on low-pressure high-density processes based on inductively coupled plasma sources (Fig. 8). Special types of these include TCP (Transformer Coupled Plasma) by LAM Research, HDP (High Density Plasma) by Applied Materials which is now called DPS (Decoupled Plasma Source), ICP (Inductive Coupled Plasma) by Electrotech, MORI by Plasma Materials and Technologies, Helicon by Lucas Labs as well as the shielded plasma source by Prototech. The most-purchased ICP system now is the LAM TCP 9600. It is a single-wafer stand-alone system with an integrated RF downstream stripper (DSQ, Decoupled Source Quartz) and an integrated water rinse module (APM, Atmospheric Pressure Module). The operation pressure is between 1 and 25 mTorr. Recommended chemistries are Cl_2/BCl_3 and a new and improved Cl_2/HCl . Alternative approaches to generate a high-density plasma are MCR (Magnetically Confined Reactor), a magnetically enhanced triode reactor by TEGAL, or the ECR sources (Electron Cyclotron Resonance) from Leybold, Hitachi and Sumitomo.

3. Aluminum CMP

Besides RIE, chemical mechanical polishing (CMP) can be used for patterning and planarization of layers [12]. In the CMP approach the wafer is fixed on a rotating wafer carrier (Fig. 9). The wafer carrier with the wafer is pressed on a rotating table with a polishing pad. Due to these two rotations, the wafer surface is ground. The grinding process is chemically enhanced by a slurry which is injected onto the polishing pad. The slurry consists of small particles to improve the grinding process and an etchant which reacts favourably with the material to be removed and not with the underlying material. Thus, a selective removal of layers is possible.

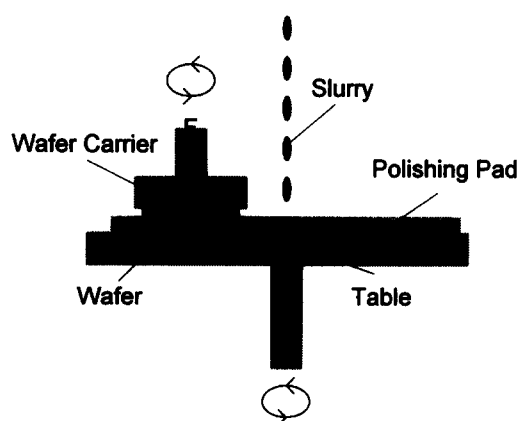


Fig. 9. Schematics of the CMP approach.

CMP was originally developed for planarization of dielectric layers like SiO_2 [63–66], but can also be used for patterning of multilevel metallization [13,14]. A typical process sequence is the ‘Dual Damascene Process’ [14], as shown in Fig. 10. In a first step, the ILD oxide is deposited (Fig. 10a). After the contact hole lithography (Fig. 10b), the contact hole is etched by oxide RIE (Fig. 10c). Subsequent to the photoresist strip (Fig. 10d), a second lithography is generated for the definition of the metal structures (Fig. 10e). The metal structures are etched into the oxide with a timed RIE process (Fig. 10f). The etch time in combination with the etch rate defines the depth of the structures. After photoresist strip (Fig. 10g) the aluminum is deposited (Fig. 10h). The deposition method depends on the feature size. While for geometries of $0.8\text{ }\mu\text{m}$ and larger normal PVD can be used, the step coverage for smaller structures is not sufficient. Here, methods like collimated sputtering, hot aluminum deposition or ForceFill are appropriate. A barrier layer is not necessary in the displayed sequence because the contacts connect a tungsten wire and not an active area in the silicon. The metal structures are finally generated by the aluminum CMP process (Fig. 10i). For a better selectivity to the oxide, a special CMP stop, i.e. a tungsten layer, can be applied. The sequence ends up with a planar surface after a second oxide deposition (Fig. 10j).

In Fig. 11, a multilevel metallization consisting of metal layers fabricated with the Dual Damascene sequence and the RIE sequence is displayed [13]. The Metal 1 layer fabricated by CMP shows a planar and smooth surface while the Metal 2 which is fabricated by RIE shows topography. It should be noted that this is a metallization for 256 M DRAM with ground rules of $0.25\text{ }\mu\text{m}$.

Table 1 shows a comparison of process steps for the Dual Damascene and the RIE sequence. The Dual Damascene sequence has 6 process steps less than the RIE sequence. This leads to a module cost reduction of 13% and a module process time reduction of 18% for a 256 M DRAM [13].

4. Conclusion

Metal RIE is a well-known and proven technology. Two factors, the process chemistry, and the reactor type (equipment) have major influence on the process results. As chemistry, chlorine-based etchants are state-of-the-art. Widely used mixtures are Cl_2/BCl_3 with optional additions of nitrogen

Fig. 10.a	ILD-Oxide Deposition	
Fig. 10.b	Lithogr. Contact Holes	
Fig. 10.c	Contact Hole Etch	
Fig. 10.d	Photoresist Strip	
Fig. 10.e	Lithogr. Metal Lines	
Fig. 10.f	Oxide-RIE	
Fig. 10.g	Photoresist Strip	
Fig. 10.h	Aluminum Deposition	
Fig. 10.i	Aluminum CMP	
Fig. 10.j	Oxide-Dep.	

Fig. 10. The Dual Damascene sequence.

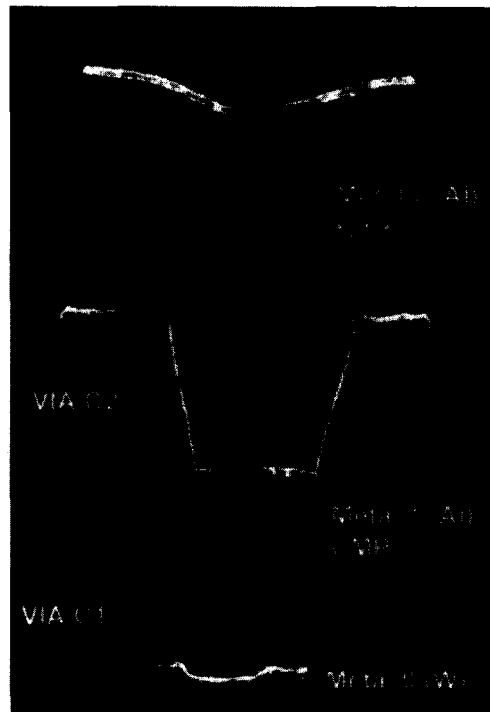


Fig. 11. 256 M DRAM multilevel metallization consisting of metal layers fabricated with CMP and RIE [13].

Table 1

Comparison of process steps for the RIE and the Dual Damascene sequence

	RIE process	Dual Damascene process
1	Oxide (USG) deposition	Oxide (USG) deposition
2	Lithography contact holes	Lithography contact holes
3	Contact hole etch	Contact hole etch
4	Photoresist strip	Photoresist strip
5	Ti/TiN deposition	Lithography metal 1
6	Tungsten-deposition	Oxide etch for metal 1
7	Tungsten-CMP	Photoresist strip
8	Metal 1 deposition	Hot aluminum deposition (metal 1)
9	Lithography metal 1	Metal 1 CMP
10	Metal 1 RIE	Oxide (USG) deposition
11	Photoresist strip	
12	Anneal	
13	Oxide (DFSG) dep.	
14	Oxide CMP	
15	Densification anneal	
16	Oxide (USG) deposition	

and CH_4 . Bromine-based chemistries have been investigated but are still far away from the breakthrough. Iodine-based chemistries with HI as etchant are very new but show very promising results in terms of photoresist selectivity, selectivity to the barrier layer (etch stop) and profile control. With a more intense evaluation, HI may be a good alternative to chlorine-based etchants.

In the field of equipment, older diode systems especially Hexode systems are still in production. More sophisticated MERIE systems can improve performance but still show some shortcomings. Newer low-pressure high-plasma-density approaches based on the ICP technology are going to become state-of-the-art.

In comparison to the RIE sequence the Dual Damascene approach shows distinctively fewer process steps. This leads to a module cost reduction of more than 10% and a reduction in module cycle times of nearly 20%. On the other hand, metal CMP is not a proven technology. Aluminum is soft, tends to smear, and is, therefore, 'not the best' material for CMP. Nevertheless, considering the great benefits in terms of costs and cycle times, metal CMP may become state-of-the-art for aluminum patterning. However, an intense evaluation and verification in a tough production environment is necessary.

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