STABILIZED PHOTORESIST STRUCTURE FOR ETCHING PROCESS

BACKGROUND OF THE INVENTION

[0001] The present invention relates to the formation of semiconductor devices.

[0002] During semiconductor wafer processing, features of the semiconductor device are defined in the wafer using well-known patterning and etching processes. In these processes, a photoresist (PR) material is deposited on the wafer and then is exposed to light filtered by a reticle. The reticle may be a transparent plate that is patterned with exemplary feature geometries that block light from propagating through the reticle.

[0003] After passing through the reticle, the light contacts the surface of the photoresist material. The light changes the chemical composition of the photoresist material such that a developer can remove a portion of the photoresist material. In the case of positive photoresist materials, the exposed regions are removed, and in the case of negative photoresist materials, the unexposed regions are removed. Thereafter, the wafer is etched to remove the underlying material from the areas that are no longer protected by the photoresist material, and thereby define the desired features in the wafer.

[0004] Various generations of photoresist are known. 193 nm and higher generation photoresist materials have been found to have problems being soft resulting in low etch selectivity, line edge roughness, striation, and line wiggling. Line edge roughness may be due to modifications to the photoresist mask, such as chemically etching away part of the photoresist mask or may be due to non-uniform polymer deposition. Non-uniform polymer deposition may be dependent on gases used, surface material polymer sticking coefficients, or resputtering. Line wiggling is believed to be related to stress caused by deposition of material on the photoresist mask. Non-uniform deposition on the photoresist mask may cause line wiggling stress. Problems that may be encountered during this process are striation and limitations on critical dimensions (CD).

SUMMARY OF THE INVENTION

[0005] To achieve the foregoing and in accordance with the purpose of the present invention a method for forming features in an etch layer is provided. A first mask is formed over the etch layer wherein the first mask defines a plurality of spaces with widths. The first mask is laterally etched where the etched first mask defines a

plurality of spaces with widths, wherein the widths of the spaces of the etched first mask are greater than the widths of the spaces of the first mask. A sidewall layer is formed over the etched first mask wherein the sidewall layer wherein the sidewall layer defines a plurality of spaces with widths that are less than the widths of the spaces defined by the etched first mask. Features are etched into the etch layer through the sidewall layer, where the features have widths that are smaller than the widths of the spaces defined by the etched first mask. The mask and sidewall layer are removed.

[0006] In another manifestation of the invention, a method for forming features in an etch layer is provided. A plurality of vias are etched into the etch layer. A trench photoresist mask is formed. A sidewall layer is formed over the trench mask and on sidewalls of the plurality of vias. Trenches are etched into the etch layer through the sidewall layer.

[0007] In another manifestation of the invention a method for etching a feature in an etch layer is provided. A patterned photoresist mask is formed over the etch layer with photoresist features with sidewalls wherein the sidewalls of the photoresist features have striations forming peaks and valleys. The striations of the sidewalls of the photoresist features are reduced. The reducing the striations comprises at least one cycle, wherein each cycle comprises etching back peaks formed by the striations of the sidewalls of the photoresist features and depositing on the sidewalls of the photoresist features. Features are etched into the etch layer through the photoresist features. The photoresist mask is removed.

[0008] In another manifestation of the invention a method of etching features in an etch layer disposed below a patterned photoresist mask with photoresist features with sidewalls wherein the sidewalls of the photoresist features have striations forming peaks and valleys is provided. The striations of the sidewalls of the photoresist features are reduced comprising at least one cycle, wherein each cycle comprises providing a striation peak etch back gas, generating a plasma from the striation peak etch back gas, stopping the striation peak etch back gas, providing a photoresist feature sidewall deposition gas, generating a plasma from the photoresist feature sidewall deposition gas, and stopping the photoresist feature sidewall deposition gas. The etch layer is etched. The photoresist mask is removed.

[0009] In another manifestation of the invention an apparatus for etching a feature

in an etch layer, below a photoresist mask with photoresist features with sidewalls with striations forming peaks and valleys is provided. A plasma processing chamber, comprising a chamber wall forming a plasma processing chamber enclosure, a substrate support for supporting a substrate within the plasma processing chamber enclosure, a pressure regulator for regulating the pressure in the plasma processing chamber enclosure, at least one electrode for providing power to the plasma processing chamber enclosure for sustaining a plasma, a gas inlet for providing gas into the plasma processing chamber enclosure, and a gas outlet for exhausting gas from the plasma processing chamber enclosure is provided. A gas source is in fluid connection with the gas inlet, where the gas source comprises a striation peak etch back gas source, a photoresist feature sidewall deposition gas source, and an etch layer etch gas source. A controller is controllably connected to the gas source and the at least one electrode. The controller comprises at least one processor and computer readable media. The computer readable media comprises computer readable code for reducing the striations of the photoresist features, comprising a plurality of cycles, wherein each cycle comprises computer readable code for providing a striation peak etch back gas from the striation peak etch back gas source, computer readable code for generating a plasma from the striation peak etch back gas, computer readable code for stopping the striation peak etch back gas from the striation peak etch back gas source, computer readable code for providing a photoresist feature sidewall deposition gas from the photoresist feature sidewall deposition gas source, computer readable code for generating a plasma from the photoresist feature sidewall deposition gas, and computer readable code for stopping the photoresist feature sidewall deposition gas from the photoresist feature sidewall deposition gas. The computer readable media further comprises computer readable code for etching the etch layer and computer readable code for removing the photoresist mask.

[0010] These and other features of the present invention will be described in more detail below in the detailed description of the invention and in conjunction with the following figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

[0012] FIG. 1 is a high level flow chart of a process that may be used in an embodiment of the invention.

[0013] FIGS. 2A-D are schematic cross-sectional views of an etch layer processed according to an embodiment of the invention.

[0014] FIG. 3 is a high level flow chart of a process that may be used in another embodiment of the invention.

[0015] FIGS. 4A-H are schematic cross-sectional views of an etch layer processed according to another embodiment of the invention.

[0016] FIG. 5 is a more detailed flow chart of the step of depositing a sidewall layer.

[0017] FIG. 6 is a schematic view of a plasma processing chamber that may be used in practicing the invention.

[0018] FIGS. 7A-B illustrate a computer system, which is suitable for implementing a controller used in embodiments of the present invention.

[0019] FIGS. 8A-C are cross-sectional views of depositions.

[0020] FIG. 9 is a high level flow chart of a process that may be used in an embodiment of the invention.

[0021] FIG.'s 10A-I are schematic cross-sectional and top views of a stack processed according to an embodiment of the invention.

[0022] FIG. 11 is a more detailed flow chart of a step of reducing striation.

[0023] FIG. 12 is a schematic view of a plasma processing chamber that may be used in practicing the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0024] The present invention will now be described in detail with reference to a few preferred embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention.

[0025] The invention provides features with small critical dimensions (CD). More specifically, the invention provides features with CD's that are less than the CD of the photoresist pattern used to etch the feature.

[0026] To facilitate understanding, FIG. 1 is a high level flow chart of a process that may be used in an embodiment of the invention. A first mask is formed over an etch layer disposed over a substrate (step 104). FIG. 2A is a cross-sectional view of a patterned mask in an embodiment of the invention. Over a substrate 204, such as a wafer a barrier layer 206 may be placed. Over the barrier layer 206 an etch layer 208 such as a conductive metal layer or a polysilicon layer or a dielectric layer is formed.. Over the etch layer 208 an antireflective layer (ARL) 210 such as a DARC layer is formed. A patterned first mask 212 is formed over the ARL 210. The spaces 222 in the photoresist mask have a width "S_p", as shown.

[0027] The first photoresist mask is laterally etched (step 108) so that spaces 224 in the etched first photoresist mask 214 have widths "S_e" that are greater than the widths "S_p" of the spaces in the etched first mask, as shown in FIG. 2B. In the specification and claims, a lateral etch is defined as an etch of sides of a mask which form spaces (apertures), wherein the lateral etch increases the size of the spaces. For a trench mask, such a lateral etch may be a trimming of the trench mask. Such lateral etches may also reduce the thickness of the mask.

[0028] A sidewall layer is formed over the mask to reduce the widths of the spaces in the etched first mask (step 112). FIG. 2C is a schematic cross-sectional view of the etched first photoresist mask 214 with a sidewall layer 218 deposited over the sidewalls of the etched first photoresist mask 214. The sidewall layer 218 forms reduced spaces 226. In this example, the spaces 226 formed by the sidewall layer 218 have widths S_s, which are about equal to the widths S_p of the photoresist mask. It is also desirable that the sidewall layer has substantially vertical sidewalls, which are highly conformal as shown. An example of a substantially vertical sidewall is a sidewall that from bottom to top makes an angle of between 88° to 90° with the bottom of the feature. Conformal sidewalls have a deposition layer that has substantially the same thickness from the top to the bottom of the feature. Non-conformal sidewalls may form a faceting or a bread-loafing formation, which provide non-substantially vertical sidewalls. Tapered sidewalls (from the faceting formation) or bread-loafing sidewalls may increase the deposited layer CD and provide a poor

etching mask. Preferably, the deposition on the side wall is thicker than the deposition on the bottom of the first mask feature. More preferably, no layer is deposited over the bottom of the first mask feature. In this example, the sidewall layer 218 also forms a layer over the top of the photoresist mask 214 as shown. In other embodiments, the sidewall layer does not form a layer over the top of the photoresist mask.

[0029] Features are then etched into the etch layer 208 through the sidewall layer spaces (step 116). FIG. 2D shows a set of features 232 etched into the etch layer 208.

[0030] The sidewall layer 218 is of a material that is more etch resistant than the photoresist mask 214, allowing for increased etch selectivity. In addition, the sidewall layer is made of a material that is chosen to prevent photoresist line wiggling, line edge roughness, and striation.

[0031] The sidewall layer and photoresist mask are then removed (step 120). Preferably, a single mask stripping step in the etch chamber is used to both strip the photoresist mask and sidewall layer.

Via First Dual Damascene Embodiment

[0032] In another embodiment of the invention, the invention is used in a dual damascene via first process. FIG. 3 is a high level flow chart of the process used in this embodiment. A first mask is formed over an etch layer disposed over a substrate (step 304). FIG. 4A is a cross-sectional view of a patterned mask in an embodiment of the invention. Over a substrate 404, such as a wafer a barrier layer 406 may be placed. Over the barrier layer 406 an etch layer 408 such as a dielectric layer is formed. Over the etch layer 408 an antireflective layer (ARL) 410 such as a DARC layer is formed. A patterned first mask 412 is formed over the ARL 410. In this embodiment, the first mask is a via mask. The first mask has at least one space 422 for forming a via.

[0033] The first photoresist mask is laterally etched (step 308) so that spaces 424 in the etched first photoresist mask 414 have widths that are greater than the widths of the spaces in the etched first mask, as shown in FIG. 4B. A sidewall layer 414 is formed over the mask to reduce the widths of the spaces in the etched first mask (step 312). First features 432 are then etched into the etch layer 408 through the sidewall layer spaces (step 316). In this embodiment, the first features 432 are vias. The first mask and sidewall layer are then removed (step 320), as shown in FIG. 4C.

[0034] A second mask 424 is formed over the etch layer (step 324), as shown in FIG. 4D. In this embodiment, the second mask 424 is a trench mask. The second mask 424 is laterally etched (step 328), as shown in FIG. 4E. A sidewall layer 428 is formed over the etched second mask 424 and first features, as shown in FIG. 4F. Trenches 444 are etched into the etch layer 408 through the sidewall layer 428, as shown in FIG. 4G. In this embodiment, the sidewall layer 428 in the via may cause some fencing 448.

[0035] The second mask and sidewall layer are then removed (step 340), as shown in FIG. 4H. The fence may be removed during this step or may be removed with an additional step. In addition to using the sidewall layer to protect the photoresist masks to increase etch selectivity and reduce wiggling, line edge roughening, and striation, this embodiment uses the sidewall layer over the sidewalls of the vias to prevent notching and bowing of the vias during the trench etch. It is believed that etch resistant sidewall layers over the via sidewalls provide more protection to reduce or eliminate notching. The formation of sidewalls over the sidewalls of the via is advantageous over via plugs, since such sidewalls may provide an improved trench etch and are more easily removed, minimizing damage during the removal process.

Using Gas Modulation to Form Sidewalls

[0036] In the preferred embodiment, gas modulation is used to form the conformal sidewalls. Preferably the sidewalls are formed of a polymer material and the mask is a photoresist polymer, so that the deposition of the sidewall layer may be performed in situ in the same chamber were the etching and stripping are performed, and so that the stripping may remove both the mask and the sidewall layer.

[0037] FIG. 5 is a more detailed flow chart of the forming a sidewall layer over the mask (steps 112, 312, and 332), which uses gas modulation. In this embodiment, the forming the sidewall layer over the mask (steps 112, 312, and 332) comprises a deposition phase 504 and a profile shaping phase 508. The deposition phase uses a first gas chemistry to form a plasma, which deposits a sidewall layer over the sidewalls of the mask. The profile shaping phase 508 uses a second gas chemistry different than the first gas chemistry to form a plasma, which shapes the profile of the deposition.

[0038] The invention may be used for etching a dielectric layer or a conductive layer. Example recipes that may be used to practice the invention for dielectric or conductive layers are provided below:

Example Process

[0039] In an example of the inventive process, the etch layer 208 is a dielectric layer. A photoresist mask is formed over the dielectric layer 208 (step 104). The substrate 204 is then placed in a plasma processing chamber. FIG. 6 is a schematic view of a plasma processing chamber 600 that may be used for depositing the sidewall layer, etching, and stripping. The plasma processing chamber 600 comprises confinement rings 602, an upper electrode 604, a lower electrode 608, a gas source 610, and an exhaust pump 620. The gas source 610 comprises a deposition gas source 612 and a profile shaping gas source 616. The gas source 610 may comprise additional gas sources, such as an etching gas source 618. Within plasma processing chamber 600, the substrate 204 is positioned upon the lower electrode 608. The lower electrode 608 incorporates a suitable substrate chucking mechanism (e.g., electrostatic, mechanical clamping, or the like) for holding the substrate 204. The reactor top 628 incorporates the upper electrode 604 disposed immediately opposite the lower electrode 608. The upper electrode 604, lower electrode 608, and confinement rings 602 define the confined plasma volume. Gas is supplied to the confined plasma volume by the gas source 610 and is exhausted from the confined plasma volume through the confinement rings 602 and an exhaust port by the exhaust pump 620. A first RF source 644 is electrically connected to the upper electrode 604. A second RF source 648 is electrically connected to the lower electrode 608. Chamber walls 652 surround the confinement rings 602, the upper electrode 604, and the lower electrode 608. Both the first RF source 644 and the second RF source 648 may comprise a high frequency (27 to 300) MHz power source and a low frequency (2 to 14) MHz power source. Different combinations of connecting RF power to the electrode are possible. A controller 635 is controllably connected to the RF sources 644, 648, exhaust pump 620, and the gas source 610.

[0040] FIG.'s 7A and 7B illustrate a computer system 1300, which is suitable for implementing a controller 635 used in embodiments of the present invention. FIG. 7A shows one possible physical form of the computer system. Of course, the computer system may have many physical forms ranging from an integrated circuit, a

printed circuit board, and a small handheld device up to a huge super computer. Computer system 1300 includes a monitor 1302, a display 1304, a housing 1306, a disk drive 1308, a keyboard 1310, and a mouse 1312. Disk 1314 is a computer-readable medium used to transfer data to and from computer system 1300.

[0041] FIG. 7B is an example of a block diagram for computer system 1300. Attached to system bus 1320 is a wide variety of subsystems. Processor(s) 1322 (also referred to as central processing units, or CPUs) are coupled to storage devices, including memory 1324. Memory 1324 includes random access memory (RAM) and read-only memory (ROM). As is well known in the art, ROM acts to transfer data and instructions uni-directionally to the CPU and RAM is used typically to transfer data and instructions in a bi-directional manner. Both of these or other types of memories may include any suitable form of the computer-readable media described below. A fixed disk 1326 is also coupled bi-directionally to CPU 1322; it provides additional data storage capacity and may also include any of the computer-readable media described below. Fixed disk 1326 may be used to store programs, data, and the like and is typically a secondary storage medium (such as a hard disk) that is slower than primary storage. It will be appreciated that the information retained within fixed disk 1326 may, in appropriate cases, be incorporated in standard fashion as virtual memory in memory 1324. Removable disk 1314 may take the form of any of the computer-readable media described below.

[0042] CPU 1322 is also coupled to a variety of input/output devices, such as display 1304, keyboard 1310, mouse 1312, and speakers 1330, and feedback and forward system for control of the process. In general, an input/output device may be any of: video displays, track balls, mice, keyboards, microphones, touch-sensitive displays, transducer card readers, magnetic or paper tape readers, tablets, styluses, voice or handwriting recognizers, biometrics readers, or other computers. CPU 1322 optionally may be coupled to another computer or telecommunications network using network interface 1340. With such a network interface, it is contemplated that the CPU might receive information from the network, or might output information to the network in the course of performing the above-described method steps. Furthermore, method embodiments of the present invention may execute solely upon CPU 1322 or may execute over a network such as the Internet in conjunction with a remote CPU that shares a portion of the processing.

[0043] In addition, embodiments of the present invention further relate to computer storage products with a computer-readable medium that have computer code thereon for performing various computer-implemented operations. The media and computer code may be those specially designed and constructed for the purposes of the present invention, or they may be of the kind well known and available to those having skill in the computer software arts. Examples of computer-readable media include, but are not limited to: magnetic media such as hard disks, floppy disks, and magnetic tape; optical media such as CD-ROMs and holographic devices; magneto-optical media such as floptical disks; and hardware devices that are specially configured to store and execute program code, such as application-specific integrated circuits (ASICs), programmable logic devices (PLDs) and ROM and RAM devices. Examples of computer code include machine code, such as produced by a compiler, and files containing higher level code that are executed by a computer using an interpreter. Computer readable media may also be computer code transmitted by a computer data signal embodied in a carrier wave and representing a sequence of instructions that are executable by a processor. Other examples may use other deposition devices.

[0044] An example of a recipe for laterally etching the mask (steps 108, 308, and 32) provides an etch chamber or plasma processing chamber pressure of 1 to 300mT. 50 to 800 Watts of power is supplied to the plasma processing chamber at 27 MHz. 0 to 200 sccm of CF_4 and 5 to 30 sccm of O2 are provided to the plasma processing chamber. More preferably, the pressure for laterally etching the mask is between 20-150 mT.

[0045] One example of a deposition phase 504 may be CH_3F deposition using a chemistry of 250 sccm (standard cubic centimeters per minute) Ar and 50 sccm CH_3F, at a pressure of 60 mTorr, established by setting a Vat valve of the turbo pump to 1000. The 27 MHz RF source provides 500 Watts of power, while the 2 MHz RF source provides 100 Watts of power. The chamber temperature is maintained at 20° C. A helium cooling pressure, to cool the substrate is 15 Torr. Such a recipe causes the formation of a polymer sidewall layer.

[0046] One example of a profile shaping phase 508 may be $C_4F_6/O_2/CO$ deposition using a chemistry of 270 sccm Ar, 12 sccm C_4F_6, 8 sccm O_2, and 100 sccm CO, at a pressure of 50 mTorr, established by setting a Vat valve of the turbo pump to

1000. The 27 MHz RF source provides 1500 Watts of power, while the 2 MHz RF source provides 480 Watts of power. The chamber temperature is maintained at 20° C. A helium cooling pressure, to cool the substrate is 15 Torr.

[0047] FIG. 8A is a cross-sectional view of a deposition layer 820 from the deposition phase. The deposition layer 820 is formed over a mask 812. In this example, the deposition phase forms a "bread-loafing" deposition layer as indicated by outlines 824. The bread-loafing deposition layer is characterized by a thicker sidewall deposition near the top of the feature and a thinner (or no) sidewall deposition near the bottom of the feature. In addition, the bread-loafing in this example forms a layer at over the very bottom surface of the feature, as shown. Therefore, this deposition provides a non-conformal sidewall deposition. Such a deposition does not provide the desired substantially vertical sidewalls. The bread-loafing eventually pinches off the top, which then cannot be used as a masking layer, since the contact will be closed off and no etching can be done.

[0048] FIG. 8B is a cross-sectional view of a deposition layer 830 where only the profiling shaping phase is used. In this example, the profile shaping phase forms a "faceting" deposition layer, as indicated by outlines 834. The faceting deposition layer is characterized by a thinner (or no) sidewall deposition near the top of the feature and a thicker sidewall deposition near the bottom of the feature. The "faceting" deposition does not deposit at the very bottom surface of the feature. Therefore, this deposition also provides a non-conformal sidewall deposition. If the sidewalls near the top are too thin, faceting of the photoresist mask may result. Such a deposition does not provide the desired substantially vertical sidewalls. The faceting of the corners of the photoresist mask may cause lower etch selectivity and fast mask erosion. The faceting of the mask will also result in faceting of the etched profile. In almost all cases, once the mask is faceted, then the final etched profile is also faceted, since the mask vertical profile generally translates into the etched material.

[0049] FIG. 8C is a cross-sectional view of a deposition layer 840 formed by 6 cycles of a 2 second deposition and 25 second profile shaping. As can be seen, the deposition layer has vertical sidewalls and little or no deposition at the bottom surface of the feature. To provide a 6 cycle process of multiple phases, a gas-modulation device, which is able to alternate gas recipes quickly, would be a preferred apparatus.

[0050] The ability to control the ratio of the times of the deposition phase 504 and the profile shaping phase 508 provide another control variable. A proper ratio will provide substantially vertical and conformal sidewalls as illustrated in FIG. 8C. Such a deposition layer is also able to protect the photoresist mask to increase etch selectivity. Other control parameters provided by the invention that can be used to control the deposition profiles are: number of cycles, total deposition time, deposition/shaping phase time ratio, gas chemistry types, and ratios. Gas chemistries that may be used by the invention may be $C_xH_yF_z$ or C_xF_y with or without O_2 (such as CH_3F/O_2, C_4F_6/O_2 , CH_2F_2, CHF_3, CF_4) or may be H_2, CH_4, C_2H_4, SiH_4, etc. Preferably, the deposition phase uses a chemistry of a hydrocarbon and a fluorocarbon. Preferably, the hydrocarbon is at least one of CH_4 and C_2H_4. The fluorocarbon is preferably at least on of CH_3F, CH_2F_2, CHF_3, C_4F_6, and C_4F_8. Other gas mixtures that may preferably be used during the deposition phase are CF_4 and H_2. Preferably, the profile shaping phase uses a chemistry of a fluorocarbon with or without other additives. Preferably, the fluorocarbon is at least one of CH_2F_2, CHF_3, and CF_4. Preferably, the other additive is at least one of Ar, Xe, He, Ne, O_2, N_2, and H_2.

[0051] The multiphase deposition allows a profile shaping step to remove unwanted deposition. In addition, a single long deposition may cause blistering. Preferably, the profile shaping step also densifies the polymer by bombarding the polymer with ions. Using multiple cycles for forming the deposition layers also provides finer CD control. In addition, the multiple cycle multiple phase deposition provides profile control. The reduction of bread loafing reduces shading, which improves etch profiles. In addition, the multiple cycle, multiple phase deposition reduces line wiggling, which is caused by the stress of a deposition layer, which causes the photoresist lines to wiggle. In addition, the profile shaping step prevents or reduces deposition on the bottom of the mask feature, to prevent residue from the deposition, which would come from resputtered material from the deposition layer that would be at the bottom of the mask feature.

[0052] Preferably, at least two cycles are used in the forming the deposition layer. More preferably, at least six cycles are used in forming the deposition layer. Some embodiments use at least twelve cycles.

[0053] Other embodiments may use a hardmask for the mask. In such embodiments, a photoresist mask may be used to open a hardmask. The sidewall layer may be placed over the photoresist mask to reduce line wiggling, line edge roughness, and striation.

[0054] Spaces in the mask may be used to etch holes or trenches in the etch layer.

[0055] The invention may be used on many different types of plasma processing tools such as Exelan and TCP type etcher, hybrid PVD, CVD, MW, RIE, MORIE, TCP, ICP, etc.

[0056] To facilitate understanding, FIG. 9 is a high level flow chart of a process that may be used in an embodiment of the invention. A patterned photoresist mask is provided (step 904). FIG. 10A is a schematic cross-sectional view of a layer to be etched 1008 over a substrate 1004, with a patterned photoresist mask 1012 with photoresist features 1014, over an ARL 1010, over the layer 1008 to be etched forming a stack 1000. The photoresist mask has a photoresist feature critical dimension (CD), which may be the widest part of the width of the smallest possible feature. To provide the patterned photoresist mask, a photoresist layer may be first formed over the layer to be etched. Then the photoresist layer is patterned to form photoresist features with photoresist sidewalls. FIG. 10B is a top view of the photoresist mask 1012. Generally, manufacturing processes, such as lithography, may cause the features 1014 to be irregularly shaped. The dotted line circles 1016 illustrate the reticle pattern provided for the photoresist mask 1012. The actual photoresist openings may have sidewalls with peaks 1020 and valleys 1024, as shown. These peaks 1020 and valleys 1024, which cause the irregular shape that deviates from the original reticle pattern, in this case a circle, and often extends for some length along the sidewall, are called striations. The photoresist features have a diameter S_p, as shown.

[0057] The photoresist features are enlarged (step 908). In one example the photoresist features are enlarged using a laterally etched so that spaces 1024 in the photoresist features 1014 have widths "S_e" that are greater than the widths "S_p" of the photoresist features before the etch, as shown in FIG. 10C, which is a cross-sectional view of the stack after the photoresist features are enlarged. FIG. 10D is a top view of the photoresist mask 1012 of FIG. 10C. In the specification and claims, a lateral etch is defined as an etch of sides of a mask which form features, wherein the lateral etch

increases the size of the widths of the photoresist features. For a trench mask, such a lateral etch may be a trimming of the trench mask. Such lateral etches may also reduce the thickness of the mask. Preferably, the lateral etch does not etch the layer under the photoresist layer 1012. An outer dotted line circle 1017 indicates a target feature shape after the lateral etching. Other embodiments of the invention do not enlarge the photoresist features or provide enlargement after the striation reduction.

[0058] The striations are reduced (step 912). FIG. 11 is a more detailed flow chart of this step. As shown in FIG. 11, the reduction of the striations comprises at least one cycle of a cyclic process comprising the steps of etching back striation peaks and depositing on the sidewalls of the photoresist features. FIG. 10E shows a top view of the photoresist layer 1012 after an etching back of striation peaks 1020 (step 1104). Without being bound by theory, it is believed that certain etching recipes selectively etch the striation peaks. As shown in FIG, 10E, some of the striation peaks are reduced.

[0059] FIG. 10F shows a top view of the photoresist layer 1012 after depositing on the sidewall (step 1108). FIG. 10G is a top view of the photoresist layer 1012 after a plurality of cycles of etching back the striation peaks (step 1104) and depositing on the sidewall (step 1108). As shown, the striation peaks 1020 are greatly reduced, and the striation valleys 1024 are significantly filled, thus overall striations are significantly reduced.

[0060] Features 1028 are then etched into the etch layer 1008 through the photoresist mask 1012 (step 916), as shown in FIG. 10H. The photoresist mask 1012 is then removed (step 920), as shown in FIG. 10I.

Example

In an example of this process patterned photoresist layer is formed (step 904). A substrate 1004, with the etch layer 1008, an ARC layer 1010, and a patterned photoresist mask 1012 is placed in an etch chamber.

[0061] FIG. 12 is a schematic view of an processing chamber 1200 that may be used for enlarging the photoresist features, reducing striations, etching, and stripping. The plasma processing chamber 1200 comprises confinement rings 1202, an upper electrode 1204, a lower electrode 1208, a gas source 1210, and an exhaust pump 1220. The gas source 1210 comprises a deposition gas source 1212 and an etch back gas source 1216. The gas source 1210 may comprise additional gas sources, such as an

etching gas source 1218. Within plasma processing chamber 1200, the substrate 1004 is positioned upon the lower electrode 1208. The lower electrode 1208 incorporates a suitable substrate chucking mechanism (e.g., electrostatic, mechanical clamping, or the like) for holding the substrate 1004. The reactor top 1228 incorporates the upper electrode 1204 disposed immediately opposite the lower electrode 1208. The upper electrode 1204, lower electrode 1208, and confinement rings 1202 define the confined plasma volume. Gas is supplied to the confined plasma volume by the gas source 1210 and is exhausted from the confined plasma volume through the confinement rings 1202 and an exhaust port by the exhaust pump 1220. A first RF source 1244 is electrically connected to the upper electrode 1204. A second RF source 1248 is electrically connected to the lower electrode 1208. Chamber walls 1252 surround the confinement rings 1202, the upper electrode 1204, and the lower electrode 1208. Both the first RF source 1244 and the second RF source 1248 may comprise a 27 MHz power source and a 2 MHz power source. Different combinations of connecting RF power to the electrode are possible. In the case of Lam Research Corporation's Dual Frequency Capacitive (DFC) System, made by LAM Research Corporation™ of Fremont, California, which may be used in a preferred embodiment of the invention, both the 27 MHz and 2 MHz power sources make up the second RF power source 1248 connected to the lower electrode, and the upper electrode is grounded. A controller 1235 is controllably connected to the RF sources 1244, 1248, exhaust pump 1220, and the gas source 1210. The DFC System would be used when the layer to be etched 1008 is a dielectric layer, such as silicon oxide, organo silicate glass, or organic dielectric film.

[0062] The photoresist mask features are enlarged (step 908). Such an enlargement process would use, for example, an enlargement gas of at least one of CF_4, H_2, NF_3, $C_xH_yF_z$, and O_2. In one example of a recipe for mask feature enlargement provides an etch chamber or plasma processing chamber pressure of 1 to 300 mT. 50 to 800 Watts of power are supplied to the plasma processing chamber at 27 MHz. 0 to 200 sccm of CF_4 and 5 to 30 sccm of O2 are provided to the plasma processing chamber. More preferably, the pressure for laterally etching the mask is between 20-150 mT.

[0063] The striation is reduced (step 912). Using multiple cycles of the cycle shown in FIG. 11 An example recipe for the step of etching back striation peaks (step

1104) provides a halogen (i.e. fluorine, bromine, chlorine) containing gas, such as 100 sccm CF_4. In this example, CF_4 is the only gas provided during the etch back. A pressure of 20 mTorr is provided to the chamber. The second RF source 448 provides 600 Watts at a frequency of 27 MHz and 0 Watts a frequency of 2 MHz.

[0064] An example of the step of depositing on the sidewalls (step 1108) provides a flow of 150 sccm CH_3F, 75 sccm N_2, and 100 sccm Ar. The pressure is set to 80 mTorr. The substrate is maintained at a temperature of 20° C. The second RF source 448 provides 400 Watts at a frequency of 27 MHz and 0 Watts a frequency of 2 MHz.

[0065] Features are then etched into the etch layer (step 916). An example of a layer to be etched is may be a conventional etch layer, such as SiN, SiC, an oxide, or low-k dielectric. A conventional etch recipe may be used to etch the layer to be etched.

[0066] To remove the mask (step 920) an oxygen ashing may be used.

[0067] In a preferred embodiment of the invention, the enlargement of the photoresist features, reduction of striations, and etching the features into the etch layer are done in situ in the same etch chamber, as shown. Preferably, the reducing the striation is performed over at least three cycles. More preferably, the reducing the striation is performed over at least five cycles.

[0068] Preferably, the depositing provides a gas containing at least one of a hydrocarbon and fluorohydrocarbon causing the deposition of at least one of a hydrocarbon and fluorohydrocarbon on the sidewalls of the photoresist features.

[0069] While this invention has been described in terms of several preferred embodiments, there are alterations, permutations, modifications, and various substitute equivalents, which fall within the scope of this invention. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, modifications, and various substitute equivalents as fall within the true spirit and scope of the present invention.

CLAIMS

What is claimed is:

1. A method for forming features in an etch layer, comprising:

etching a plurality of vias into the etch layer;

forming a trench photoresist mask, wherein the trench photoresist mask defines a plurality of spaces with widths;

laterally etching said trench photoresist mask;

forming a sidewall layer over the trench mask and on sidewalls of the plurality of vias, wherein the sidewall layer defines a plurality of spaces having widths approximately equal to the widths of the plurality of spaces defined by the trench photoresist mask by said forming the trench photoresist mask;

etching trenches into the etch layer through the sidewall layer.

2. The method, as recited in claim 1 , wherein the forming sidewall layer over the trench mask and on sidewalls of the plurality of vias comprises at least two cycles, wherein each cycle comprises:

a deposition phase with a first gas chemistry to form a deposition plasma to form a deposition over the sidewalls of the first mask; and

a profile shaping phase with a second gas chemistry to shape the profile of the deposition over the sidewalls of the first mask, wherein the first gas chemistry is different than the second gas chemistry.

3. The method, as recited in any of claims 1-2, further comprising placing the etch layer in a plasma processing chamber wherein the forming the sidewall layer, and etching are done within the plasma processing chamber.

4. The method, as recited in any of claims 1-3, wherein the sidewall layer is of a polymer material.

5. The method, as recited in any of claims 1-4, wherein the forming the sidewall layer forms substantially vertical sidewalls.

6. The method, as recited in any of claims 1-5, further comprising stripping the photoresist mask and sidewall layer with a single stripping step.

7. The method, as recited in any of claims 1-6, wherein the stripping the photoresist mask and sidewall layer comprises ashing the photoresist mask and sidewall layer.

8. The method, as recited in claim 7, wherein the ashing the photoresist mask and sidewall layer is performed in the same plasma processing chamber as forming the sidewall layer and etching.

9. The method, as recited in any of claims 5-8, wherein the lateral etching the trench photoresist mask, comprises:

providing a halogen containing gas; and

forming a plasma from the halogen containing gas.

10. The method, as recited in any of claims 1-9, wherein the forming a sidewall layer, comprises depositing at least one of a hydrocarbon and a hydrofluorocarbon on the sidewalls of the mask features.

11. The method, as recited in any of claims 1-9, wherein the forming a sidewall layer, comprises:

providing a deposition gas comprising at least one of a hydrocarbon and a hydrofluorocarbon; and

forming a plasma from the deposition gas.

12. The method, as recited in any of claims 5-8, wherein the laterally etching comprises:

providing an etching gas;

generating a plasma from the etching gas; and

stopping the etching gas, and wherein the forming the sidewall layer, comprises:

providing a deposition gas;

generating a plasma from the deposition gas; and

stopping the deposition gas.

13. A semiconductor device formed by the method of any of claims 1-12.