- maintaining the substrate at a temperature ranging from approximately -10°C to approximately 40°C; and
- measuring the activated nitrogen containing etching compound by Quadrupole mass spectrometer, optical emission spectrometer, FTIR, or other radical/ion measurement tool.

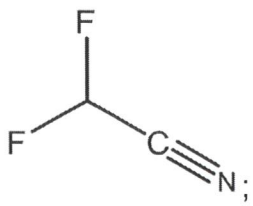
[0011a] In one aspect of the present disclosure, there is provided a method for etching silicon-containing films, the method comprising the steps of:

introducing a vapor of a nitrogen containing etching compound into a reaction chamber containing a silicon-containing film on a substrate, wherein the nitrogen containing etching compound comprises an organofluorine compound having a formula selected from the group consisting of $N\equiv C–R^1$, wherein R^1 has the formula $H_aF_bC_c$ and a=1-11, b=1-11, and c=1-5; $(N\equiv C\text{-})\text{-}(R^2)\text{-}(\text{-}C\equiv N)$, wherein R^2 has the formula $H_aF_bC_c$ with a=0, b=1-11, and c=1-5; and $R^1{}_x[\text{-}C=N(R^2{}_z)]_y$, wherein x=1-2, y=1-2, z=0-1, x+z=1-3, and each R^1 and R^2 independently has the formula $H_aF_bC_c$ with a=0-11, b=0-11, and c=0-5;

introducing an inert gas into the reaction chamber; and

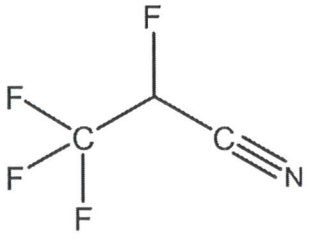
activating a plasma to produce an activated nitrogen containing etching compound capable of etching the silicon-containing film from the substrate wherein the nitrogen containing etching compound has a purity ranging from approximately 95% to approximately 99.999% by volume; and comprises between approximately 10 parts per trillion to approximately 5% by volume water vapor impurities.

[0012] Also disclosed are nitrogen containing etching compound comprising an organofluorine compound having a C≡N or C=N functional group. The disclosed nitrogen containing etching compounds include one or more of the following aspects:

- the organofluorine compound containing a C≡N functional group ;
- the organofluorine compound having the formula $N\equiv C–R^1$, wherein R^1 has the formula $H_aF_bC_c$ and a=1-11, b=1-11, and c=1-5;
- the organofluorine compound being difluoroacetonitrile (C_2HF_2N) having the formula 

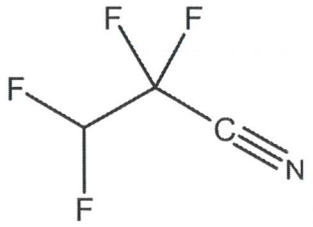
;

- the organofluorine compound being 2,3,3,3-tetrafluoropropionitrile (C_3HF_4N)

having the formula 

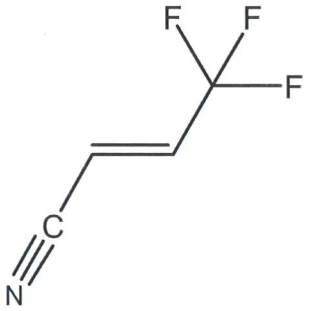
;

- the organofluorine compound being 2,2,3,3-tetrafluoropropionitrile (C_3HF_4N)

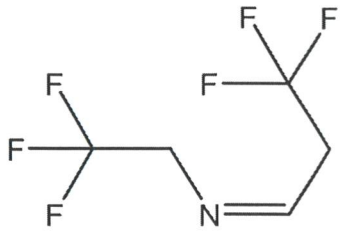
having the formula 

;

- the organofluorine compound being 4,4,4-Trifluorocrotono-nitrile ($C_4H_2F_3N$)

having the formula 

;

- the organofluorine compound being 1,1,1,6,6,6-Hexafluoro-3-azahex-3-ene ($C_5H_5F_6N$) having the formula ;
- having a purity ranging from approximately 95% to approximately 99.999% by volume;
- comprising between approximately 10 parts per trillion to approximately 5 % by volume trace gas impurities;
- the trace gas impurities comprising water;
- the trace gas impurities comprising CO_2;
- the trace gas impurities comprising N_2; and
- the nitrogen containing etching compound having a water content of less than 20 ppmw.

[0012a] In yet another aspect of the present disclosure, there is provided a nitrogen containing etching compound having a purity ranging from approximately 95% to approximately 99.999% by volume and comprising between approximately 10 parts per trillion to approximately 5% by volume water vapor impurities, the nitrogen containing etching compound comprising an organofluorine compound selected from the group consisting of difluoroacetonitrile, 2,3,3,3-tetrafluoropropionitrile, 2,2,3,3-tetrafluoropropionitrile, hexafluoroacetone imine, 4,4,4-trifluorocrotono-nitrile, 3,3,3-trifluoropropionitrile, fluoroacetonitrile, octafluorohexane-1,6-dinitrile, 1,1-bis(trifluoromethyl)-2,2-dicyanoethylene, N,1,1,1,3,3,3-heptafluoro-propanamine, and 1,1,1,6,6,6-hexafluoro-3-azahex-3-ene.

Notation and Nomenclature

[0013] The following detailed description and claims utilize a number of abbreviations, symbols, and terms, which are generally well known in the art. While definitions are typically provided with the first instance of each acronym, for convenience, Table 1 provides a list of the abbreviations, symbols, and terms used along with their respective definitions.

Table 1

a or an	one or more than one
approximately or about	±10% of the value stated
LCD-TFT	liquid-crystal display-thin-film transistor
DRAM	dynamic random-access memory
FINFET	fin-shaped field-effect transistor
Bulk CMOS	Bulk complementary metal-oxide-semiconductor
FD-SOI	fully depleted silicon-on-insulator
FEOL	front end of the line
BEOL	back end of the line
TSV	through silicon via
OLED	organic light-emitting diode
RIE	reactive ion etching

What is claimed is:

1. A method for etching silicon-containing films, the method comprising the steps of:

introducing a vapor of a nitrogen containing etching compound into a reaction chamber containing a silicon-containing film on a substrate, wherein the nitrogen containing etching compound comprises an organofluorine compound having a formula selected from the group consisting of N≡C–R^1, wherein R^1 has the formula $H_aF_bC_c$ and a=1-11, b=1-11, and c=1-5; (N≡C-)-(R^2)-(-C≡N), wherein R^2 has the formula $H_aF_bC_c$ with a=0, b=1-11, and c=1-5; and R^1_x[-C=N(R^2_z)]$_y$, wherein x=1-2, y=1-2, z=0-1, x+z=1-3, and each R^1 and R^2 independently has the formula $H_aF_bC_c$ with a=0-11, b=0-11, and c=0-5;

introducing an inert gas into the reaction chamber; and

activating a plasma to produce an activated nitrogen containing etching compound capable of etching the silicon-containing film from the substrate

wherein the nitrogen containing etching compound has a purity ranging from approximately 95% to approximately 99.999% by volume; and comprises between approximately 10 parts per trillion to approximately 5% by volume water vapor impurities.

2. The method of claim 1, further comprising removing volatile by-products from the reaction chamber, wherein the activated nitrogen containing etching compound reacts with the silicon-containing film to form the volatile by-products.

3. The method of claim 2, wherein the organofluorine compound containing the C≡N functional group has the formula: N≡C–R^1, wherein each R^1 is independently a functional group having the formula $H_aF_bC_c$ with a=1-11, b=1-11, and c=1-5.

4. The method of claim 2, wherein the organofluorine compound containing the C≡N functional group has the formula: (N≡C–)-(R^1)-(-C≡N), wherein each R^1 is independently a functional group having the formula $H_aF_bC_c$ with a=0, b=1-11, and c=1-5.

5. The method of claim 2, wherein the organofluorine compound containing the C=N functional groups has the formula: R^1_x[-C=N(R^2_z)]$_y$, wherein x=1-2, y=1-2, z=0-1, x+z=1-3, and each R^1 and R^2 independently has the formula $H_aF_bC_c$ with a=0-11, b=0-11, and c=0-5.

6. The method of claim 1, wherein the organofluorine compound is selected from the group consisting of 2,2,3,3-tetrafluoropropionitrile, 2,3,3,3-tetrafluoropropionitrile (C_3HF_4N), difluoroacetonitrile (C_2HF_2N), Hexafluoroacetone imine (C_3HF_6N); 4,4,4-Trifluorocrotono-nitrile, 3,3,3-Trifluoropropionitrile, fluoroacetonitrile, octafluorohexane-1,6-dinitrile, 1,1-bis(trifluoromethyl)-2,2-dicyanoethylene, N,1,1,1,3,3,3-heptafluoro-propanamine, and 1,1,1,6,6,6-Hexafluoro-3-azahex-3-ene.

7. The method of claim 1, wherein the organofluorine compound is 2,3,3,3-tetrafluoropropionitrile (C_3HF_4N).

8. The method of claim 1, wherein the organofluorine compound is difluoroacetonitrile (C_2HF_2N).

9. The method of any one of claims 1 to 8, further comprising introducing an oxidizer into the reaction chamber.

10. The method of any one of claims 1 to 8, wherein the silicon-containing film comprises a layer of silicon oxide, silicon nitride, polysilicon, crystalline silicon, low-*k* SiCOH, SiOCN, SiON, $Si_aO_bH_cC_dN_e$, where a>0; b, c, d and e ≥ 0, or combinations thereof.

11. The method of claim 10, wherein the silicon-containing film is selectively etched from an amorphous carbon layer or a photoresist layer.

12. The method of claim 10, wherein the silicon oxide layer is selectively etched from a silicon nitride, polysilicon or amorphous carbon layer.

13. The method of claim 9, wherein the method produces an aperture in the silicon-containing film having an aspect ratio between approximately 10:1 and approximately 200:1.

14. A nitrogen containing etching compound having a purity ranging from approximately 95% to approximately 99.999% by volume and comprising between approximately 10 parts per trillion to approximately 5% by volume water vapor impurities, the nitrogen containing etching compound comprising an organofluorine compound selected from the group consisting of

difluoroacetonitrile, 2,3,3,3-tetrafluoropropionitrile, 2,2,3,3-tetrafluoropropionitrile, hexafluoroacetone imine, 4,4,4-trifluorocrotono-nitrile, 3,3,3-trifluoropropionitrile, fluoroacetonitrile, octafluorohexane-1,6-dinitrile, 1,1-bis(trifluoromethyl)-2,2-dicyanoethylene, N,1,1,1,3,3,3-heptafluoro-propanamine, and 1,1,1,6,6,6-hexafluoro-3-azahex-3-ene.

15. The nitrogen containing etching compound of claim 14, wherein the organofluorine compound is difluoroacetonitrile or 2,3,3,3-tetrafluoropropionitrile.