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Wet-like plasma for the next generation of atomic layer etching

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In the fabrication of next-generation field effect transistor (FET) of logic semiconductor devices, the device size has been downscaled to several nanometers. Hence, selective etching of metal gate layer made of titanium compound such as ternary metal carbide TiAlC, metal nitride TiN, or metal alloy TiAl is a challenge and requires a high-performance etching technology. In our development of advanced etching methods, we have proposed the wet-dry etching or wet-like plasma etching that combines the advantages of wet etching (high isotropy and selectivity) and dry etching (high controllability). By using a floating wire-assisted vapor plasma at medium pressure, a wet-like plasma containing high-density reactive radicals can be remotely generated, this significantly increases the chemical reaction rate to the sample surface.

In traditional dry etching, halogen plasma etchants for metal and metal compounds have been used. For TiAlC material, fluorine-based plasma is not a good candidate due to forming a non-volatile product AlF_3 (boiling point (b.p.) more than 1290 °C). Chlorine-based plasma, that is normally toxic and corrosive, can form the volatile product such as $AlCl_3$ (b.p. ~ 183 °C); however, the same volatile product $TiCl_4$ (b.p. ~ 136 °C) causes poor selective etching. Here we investigate using non-halogen vapor plasmas to open a wide-range selection of environment-friendly etchants for highly selective formation of volatile products.

For dry atomic layer etching (ALE) processes such as plasma-ALE and thermal-ALE, surface modification is used to reduce surface energy of sample surface in the first step, and the modified layer with lower surface energy is removed in the next step. Here we propose a new ALE process using wet-like plasma for surface modification of metal compounds such as TiAlC by floating wire-assisted Ar/NH_4OH vapor plasma at medium pressures ranged from 0.2 kPa to 50 kPa. The high-density plasma containing NH, H, and OH can modify TiAlC surface to form volatile compounds having chemical bonds such as methyl (Al–CH_3) and methylamine (Ti–N-CH_3). By controlling the surface reactions, selective removal of TiAlC over TiN and TiAl can be achieved by the reaction with N-H-O plasma. Therefore, the wet-like plasma etching opens a new way to approach highly selective etching of metal and metal compounds with both isotropic and anisotropic behaviors for the next generation of atomic layer etching.

References
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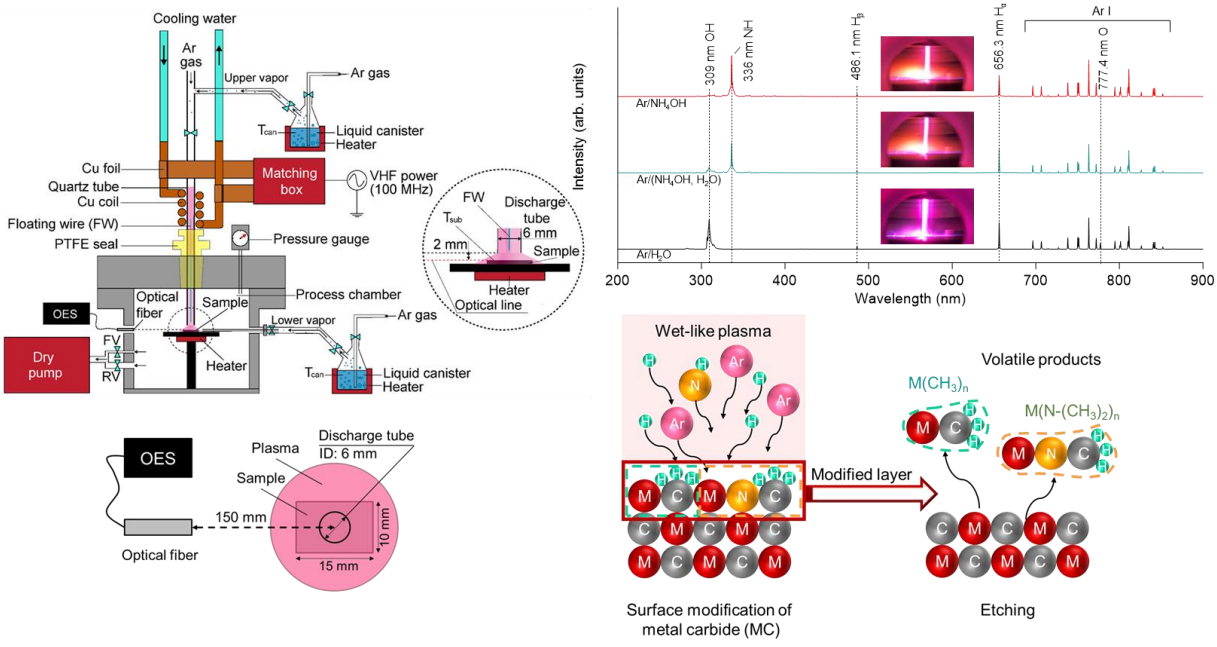

Fig. 1. Atomic layer etching of metal carbide using a wet-like plasma of Ar and NH_4OH vapor.