Investigating the Metal-plasma Interaction during the Patterning of MgZnO Alloys, used For Compute and Memory Applications

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Magnesium Zinc Oxide (MgZnO) is a novel metal alloy being considered for advanced memory applications. When used as a dielectricum in transistors in dynamic random-access memory (DRAM) [1,2] or core elements in resistive random-access memory (RRAM) [3,4], MgZnO exhibits the potential to display low cutoff current [I_{off}], high mobility [3], and low processing temperature [1]. Therefore, minimal damage-inducing patterning of the alloy for use in electrical nanoscale devices is needed.

During the etching process, MgZnO film may be chemically and physically damaged, impacting its electrical performance. Changes in chemical composition and diffusion of etchants into the material are some types of chemical damages observed during etching. These can impact carrier mobility within the material. Physical damage consists of modified roughness, profile distortion, and redeposition on the pattern sidewalls. These are all critical issues because carrier transport in transistor channels is significantly affected by interface roughness between the channel and gate insulator [5]. The etch process developed should preserve the chemical composition and roughness in MgZnO and provide good selectivity when patterning other layers of the stack and hard mask (HM). There are three methods for dry etching consisting of physical, chemical, and physical-chemical [6] mechanisms. Pure physical etching is not selective and pure chemical etching can be isotropic. Reactive ion etching (RIE) is used in this study to generate an etching mechanism that can provide an optimal combination of chemical and physical etching [6].

In this work, we carried out the etch investigation of MgZnO film using an RIE-transformer coupled plasma (TCP) system. 10 nm MgZnO films are deposited on a 50 nm SiO_2 layer/Si substrate. The impact of different gas mixing ratios, RF power, DC substrate bias, and process pressure are studied. The etching of MgZnO thin films is carried out using $Cl_2/CH_4/Ar$ mixture. Cl_2 increases chemical reactivity by creating $MgCl_2$ [7] and $ZnCl_2$ [8] by-products that are easier to remove than breaking Mg-O and Zn-O bonds from the films. Moreover, the addition of CH_4 produces organometallic volatile etch by-product – Zn $(CH_3)_2$(boiling point: 46°C) [8]. Therefore, MgZnO is to be etched partly by physical and chemical mechanisms. These observations are studied in detail by carrying out in-depth composition analysis on individual ZnO and MgO surfaces by using X-ray photoelectron spectroscopy (XPS) (Fig.1(a, b)). Besides, by increasing the voltage and power, etching performance improved due to increasing ion energy and more active species in the plasma *via* higher dissociation and ionization, respectively (Fig.1(c, d)). These investigations should enable a more systematic patterning study of MgZnO-based features at different scaled dimensions and densities.

References
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a)

Etching time	Mg	Cl	C	Si
0	14.35	0.22	31.28	0.086
30s	9.59	3.71	32.63	7.52
60s	4.76	5.76	40.07	10.41
120s	5.95	6.44	40.15	11.85

b)

Etching time	Zn	Cl	C	Si
0	33.53	0.35	20.01	1.85
30s	0.16	0.16	11.67	29.69

Green arrow→ Increasing concentration
Red arrow→ decreasing concentration

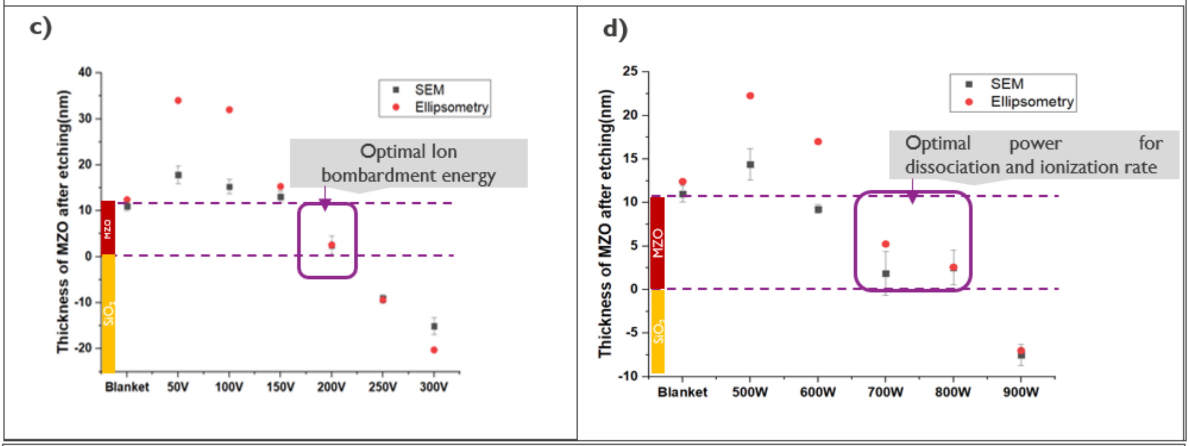

Fig.1: Change in atomic concentration of (a) Mg and (b) Zn with time after etching MgO and ZnO films, respectively with $Cl_2/CH_4/Ar$. In MgO, there is carbon-based deposition from CH_4. No such observation is reported for ZnO films indicating the formation of $Zn(CH_3)_2$-like by-product. MgZnO thickness measurements after different etching conditions to identify optimal (a) ion energy and (b) plasma power for its patterning.