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論文 / 著書情報
Article / Book Information

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著者(和文)	TSAI Sung-Lin
Author(English)	Sung-Lin Tsai
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種別(和文)	論文要旨
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（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子　　系 電気電子　　コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
学生氏名： Student's Name	TSAI Sung-Lin	指導教員（主）： Academic Supervisor(main)	角嶋　邦之
		指導教員（副）： Academic Supervisor(sub)	

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Non-volatile memory has been an important part of internet-of-things (IoT) devices. Among the non-volatile memories, ferroelectric non-volatile memories are expected to show low power consumption owing to their electric field operation. Ferroelectric random-access-memory (FeRAM) with perovskite materials has been commercialized in the past. However, it has reached its limit in thickness scaling at a relatively thick region of 100 nm. Therefore, new materials have been required to overcome the thickness scaling, enabling high-density FeRAM. A new nitride-based ferroelectric material, $Al_{1-x}Sc_xN$, has been reported in 2019 with its high remanent polarization. Also, a recent study shows that $Al_{1-x}Sc_xN$ films exhibit ferroelectricity with a thickness down to 9 nm. As $Al_{1-x}Sc_xN$ films are quite new, there is no study detailed study to be used for memory applications; including reliability, switching cycle endurance, breakdown, and also change in the property by thickness scaling.

The purpose of the thesis is to understand the degradation and breakdown mechanism of AlScN films. And to propose a process for high-reliable films with thickness scaling capability.

The process used in this study is reactive sputtering with an AlSc alloy target. A gas mixture of Ar, N_2, and/or O_2 was used to deposit the films. The wurtzite structure of AlScN has been confirmed with the grain size of 50 nm×20 nm. Low-temperature deposited 50-nm-thick AlScN MIM capacitors also showed ferroelectricity with a remanent polarization of 80 $\mu C/cm^2$ and a coercive field of 5.8 MV/cm on a CMOS-compatible metal electrode. The *CV* measurements also show poling-free behavior for AlScN MIM capacitors whose surface of AlScN films is N-face.

Reliability and breakdown mechanism evaluated by leakage current analysis upon different switching cycling. Continuous effective Schottky barrier height at AlScN/metal interface was extracted, and the local conduction path was hardly formed. The degradation is different from oxide-based ferroelectric films, where oxygen defect-mediated local conduction takes place. Moreover, AlScN films break down by Joule heat once the leakage current exceeds a certain level due to a reduction in the barrier height. The extracted model suggests the need for treatments at AlScN/metal interface.

Thickness scaling for AlScN films has revealed less oriented growth and elongation in the c-axis lattice. Remanent polarization was found to be reduced under switching at a constant electric field. This fact suggests the increase in the coercive field due to the strain in the AlScN film near the AlScN/metal interface.

Oxygen atoms incorporation to form AlScON films was found to be effective in reducing the coercive field. As the excess incorporation leads to the formation of $AlScO_3$ in the film, the content of oxygen atoms should be optimized. Under composition of $Al_{0.7}Sc_{0.3}O_{0.2}N_{0.8}$, the coercive field was reduced from 3.8 to 2.8 MV/cm. However, the increase in the coercive field upon thickness scaling is still observed. This fact indicates that stress cannot be relaxed by oxygen incorporation.

A concept of stacking of AlScON/AlScN is evaluated for the purpose to suppress the leakage

current keeping the low coercive field. From different stacking sequences, it was found that the coercive field is determined by the bulk layer; the AlScON layer. With a stacked structure, ferroelectricity showed with a 6.7-nm-thick device under 5 V operation, which is promising for memory applications. Switching cycle endurance was slightly improved with the $Al_{0.7}Sc_{0.3}N$ barrier layer, owing to the rigid interface with the low coercive field of the bulk $Al_{0.7}Sc_{0.3}O_{0.2}N_{0.8}$ layer.

In conclusion, ferroelectricity was confirmed with the low-temperature process (RT), which means it is suitable for resin substrates for future memory applications. The wake-up effect is modeled by V_N formation to lower the E_c, and fatigue is explained by electron trapping. The breakdown is triggered by the excess reduction in effective Schottky barrier height at AlScN/metal interface. Strain near the bottom electrode increases the E_c, leading to a reduction in P_r under constant E-field operation. AlScON with optimum O atoms can reduce the E_c, at the cost of leakage current. $Al_{0.7}Sc_{0.3}O_{0.2}N_{0.8}$ on an $Al_{0.7}Sc_{0.3}N$ barrier layer enables the thickness scaling down to 12 nm, with <5 V operation. More research is needed for the barrier layer for thickness scaling.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

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