Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 770-771

C-9-4

Control of 2 type Dielectric Relaxation Current of Ta_2O_5 Metal-Insulator-Metal[MIM]Capacitors

Masahiro Kiyotoshi, Katsuhiko Hieda, Yoshiaki Fukuzumi, Yusuke Kohyama,
Toshiya Suzuki*, Daisuke Matsunaga* and Koichi Hashimoto*

Toshiba Corporation, 8,Shinsugita-cho, Isogo-ku, Yokohama, 235-8522 Japan,
*Fujitsu Limited, 50, Fuchigami, Akiruno, 197-0833 Japan
Phone:(81)45-770-3661, Fax(81)45-770-3577, E-mail:kiyotoshi@amc.toshiba.co.jp

1. Introduction

Ta_2O_5 is the most promising high-k dielectric candidate for high capacitance density metal-insulator-metal (MIM) capacitor for DRAM or mixed-signal applicaton. However, it has been reported that high-k dielectrics such as Ta_2O_5 show relatively large dielectric relaxation currents (DR) which will cause the irrecoverable stored charge loss equivalent to the charge leakage, although the t^{-1} type DR are observed for almost all dielectrics (SiO_2, SiN, Ta_2O_5, BST, etc.) [1,2]. Thus, DR control will become a key issue for employing Ta_2O_5. However, the origin of DR has been not so clear. We have made a detailed study of the Ta_2O_5 DR and found the existence of 2 independent DR mechanism. The reduction of DR related to capacitor charge loss is proposed.

2. Experimental Details

Ru/Ta_2O_5/Ru liner-supported cylindrical (LSC) capacitors were employed for MIM capacitor test structures. Ta_2O_5 was deposited by LPCVD and was annealed in O_3 ambient. Ta_2O_5 thickness was around 12nm. These cylindrical capacitors were covered with passivation SiO_2 deposited by plasma CVD, and aluminium metallization had been applied to them[3]. For some of samples, post-treatment (annealing) was done under deoxidization condition to imitate back-end of line (BEOL) induced damages. Figure 1 shows the typical structure of our samples.

DR of Ta_2O_5 MIM capacitors were evaluated by *I-t* measurement. We assume that the measured current is represented by the sum of 2 components as follows;

$$I = Ii + Ir = Ii + I_0 t^{-\alpha} \quad , \tag{1}$$

where *Ii* denotes intrinsic leakage and *Ir* denotes DR current. We have made fitting of the measured *I-t* curve to Equation (1) and have calculated I_0 and α of DR from the fitted curve.

3. Results and Discussions

Figure 2 shows the I_0 of Ta_2O_5 DR (no post-treatment) for different measuring temperatures. I_0 becomes linear to the bias voltage and shows no polarity dependence. Namely, DR can be expressed as the following expression;

$$Ir = I_0 t^{-\alpha} = C_0 V t^{-\alpha} \quad . \tag{2}$$

It means DR is not influenced by electrode interface. Thus, relaxation current cannot be a real injection current, but is supposed to be a charging current into slow response parasitic capacitances. The bias voltage dependence of the exponent α is shown in Fig.3. α is almost 1 and is independent of bias voltage, but slightly decreases as temperature increases; these results are almost consistent with the systematic study of DR by H.Reisinger et al [1]. The calculated activation energy of C_0 is 0.13eV as shown in Fig.4, therefore DR is supposed to originate from electron polarization because its activation energy is very low.

However, it was found that DR of the post-treatment sample showed much smaller α (~0.5) and larger C_0 than no treatment sample especially at 85°C as shown in Fig.5. Therefore, we have executed detailed *I-t* measurements for wide measuring temperature range (-180°C to +145°C) to investigate the properties of deoxidized Ta_2O_5 DR. The C_0 and α of deoxidized Ta_2O_5 are shown in Fig.6 and Fig.7 as a function of temperature, respectively. As shown in Fig.6 and Fig.7, it is understood that deoxidized Ta_2O_5 DR is composed of 2 components. One component shows t^{-1} type time decay and slight temperature dependence of C_0. The other shows $t^{-0.5}$ type time decay and large temperature dependence that will become dominant at high temperature as 85°C. The former is supposed to be universal DR and its C_0 is almost same as that of NO film (C_0~$3X10^{-17}$) [1].

In order to explain this t^{-1} type DR, several models have been proposed. However, there has been no agreed physical model to explain t^{-1} type decay [1]. We have found that a very simple model can explain this t^{-1} type dependence.

First, it is assumed that *I-t* characteristics are expressed by the integral of distributed response of Ta_2O_5 electron polarizations. Each electron polarization is characterized by response constant τ, and τ distribution is represented by the distribution function $D(\tau)$;

$$I(t) \propto \int_0^\infty e^{-\frac{t}{\tau}} D(\tau) d\tau \quad . \tag{3}$$

Next, it is assumed that $D(\tau)$ is popular Lorentzian distribution, then eq. (3) can be divided in two parts. One is the fast response part that cannot be measured, and the other is the slow response part that is measured by normal *I-t* measurements.

$$I(t) \propto \int_0^{\tau_D} e^{-\frac{t}{\tau}} D(\tau) d\tau + \int_{\tau_D}^\infty e^{-\frac{t}{\tau}} \frac{1}{\tau^2} d\tau, \quad D(\tau)\big|_{\tau >> \tau_D} \propto \frac{1}{\tau^2 + {\tau_D}^2} \quad . \tag{4}$$

The slow response part of $I(t)$ ($=Ir(t)$) becomes as follows;

$$Ir(t) \propto \int_{\tau_D}^\infty e^{-\frac{t}{\tau}} \frac{1}{\tau^2} d\tau, \quad x = \frac{t}{\tau}, \quad \frac{dx}{d\tau} = -\frac{t}{\tau^2} \quad ,$$

$$= -\int_{t/\tau_D}^0 e^{-x} dx = \frac{1}{t}\left[1 - e^{-\frac{t}{\tau_D}}\right] \cong \frac{1}{t} \quad . \tag{5}$$

If $D(\tau)$ of different dielectric film is same Lorentzian type as Ta_2O_5, its *I-t* characteristics should be same t^{-1} type even though its τ_D is different. Supposedly, that is the reason why t^{-1} type DR is found for various materials and seems a universal phenomenon.

On the other hand, this model cannot explain the latter $t^{-0.5}$ type, and its proper model has not been found yet. This component may be characteristic of Ta_2O_5 DR, moreover it will cause the effective charge loss in contrast with t^{-1} type DR. Namely, the large activation energy (~0.4eV) of the post-treatment sample shown in Fig.6 suggests DR will cause about 16% DRAM stored charge loss at 85°C at which device operation must be guaranteed, since the "written" charge during 10ns will be re-distributed between the quick capacitor and the slow parasitic capacitor, but the charge stored in the slow capacitor cannot be "read out" during 10ns read time as shown in Fig.8.

This $t^{-0.5}$ type DR is supposed to originate from incorporated hydrogen in Ta_2O_5 film, therefore hydrogen anneal out after passivation SiO_2 formation was tried with 400°C N_2 annealing.

Figure 9 shows the *I-V* curves of post-treated sample and additionally N_2 annealed post-treated sample. Leakage current is reduced by N_2 annealing. Both C_0 and its activation energy are also reduced as shown in Fig.10, so hydrogen anneal out will be a useful method for the DR reduction.

4. Conclusion

Dielectric relaxation (DR) currents of Ta_2O_5 MIM capacitors were discussed. Ta_2O_5 DR is found to be composed of 2 components. One component shows t^{-1} type time decay, which is a universal phenomenon of dielectrics caused by ununiformity of electron polarization, and it is slightly dependent on device operation temperature , thus its influence on DRAM operation will be not so different as conventional NO films. The other shows $t^{-0.5}$ type time decay and large temperature dependence caused by incorporated hydrogen in Ta_2O_5. The latter component will have a crucial influence on the DRAM operation especially at a high temperature (85°C), so its control will become a key issue for employment of Ta_2O_5 MIM capacitors. Hydrogen anneal out is a possible solution for reduction of this $t^{-0.5}$ type DR.

Acknowledgements

We would like to express our special thanks to Dr.Nitayama (Toshiba Corporation) and Dr.Nara (Fujitsu Limited) for their sincere supports and valuable advices.

References

1. H.Reisinger, G.Steinlesberger, S.Jakschik, M.Gutsche, T.Hecht, M.Leonhard, U.Schroeder, H.Seidl, D.Schumann: IEDM Technical Digests (2001) p.267.
2. M.Schumacher and R.Waser: Integrated Ferroelectrics 22 (1988) p109.
3. Y.Fukuzumi, T.Suzuki, A.Sato, Y.Ishibashi, A.Hatada, K.Nakamura, K.Tsunoda, M.Fukuda, J.Lin, M.Nakabayashi, H. Minakata, A.Shimada, T.Kurahashi, H.Tomita, D.Matsunaga, K.Hieda, K.Hashimoto, S.Nakamura and Y.Kohyama :IEDM Technical Digests (2000) p.793.

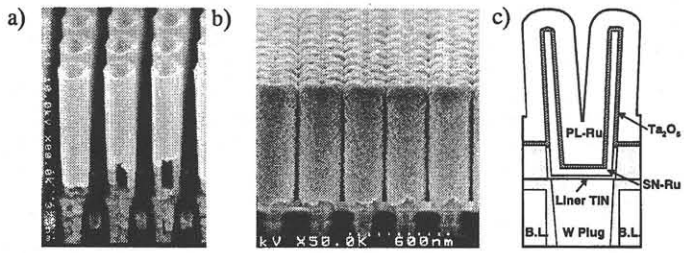

Fig.1 Typical test structure of Ta_2O_5 LSC MIM capacitors, a) after SN formation, b) after PL formation. c) schematic view.

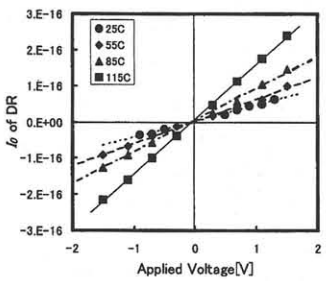

Fig.2 Bias voltage dependence of I_0 (no treatment).

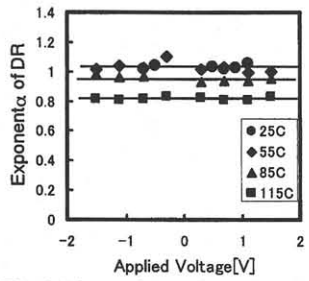

Fig.3 Bias voltage dependence of exponent α (no treatment).

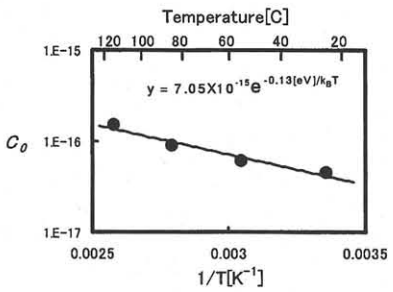

Fig.4 Arrhenius plot of C_0 of DR.

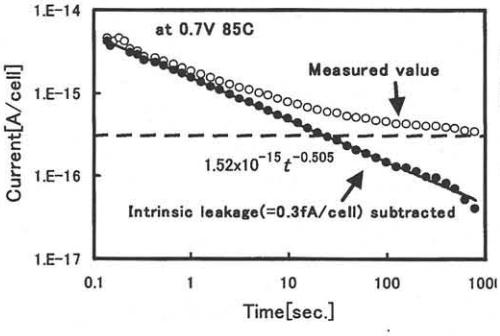

Fig.5 DR of post-treatment (deoxidized)sample.

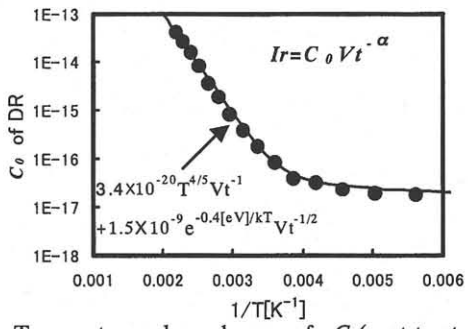

Fig.6 Temperature dependence of C_0(post-treatment sample) and fitting to our 2 components model.

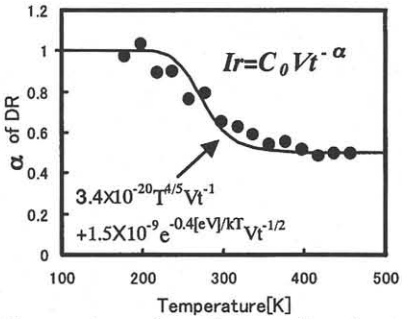

Fig.7 Temperature dependence of α (post-treatment sample) and fitting to our 2 components model.

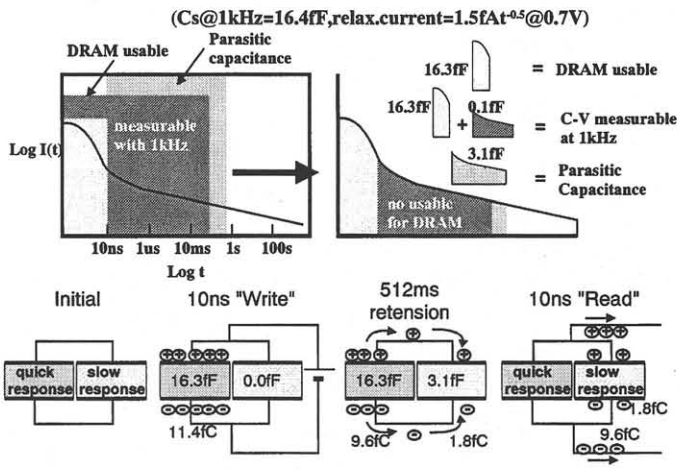

Fig.8 Schematic diagram of the DR influence on DRAM operation.

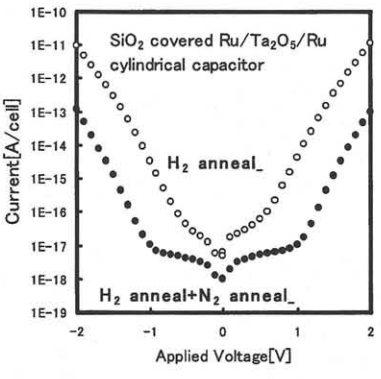

Fig.9 Post-N_2 anneal effect on *I-V* characteristics.

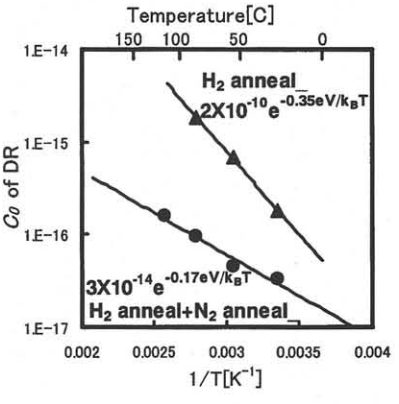

Fig.10 Post-N_2 anneal effect on temperature dependence of C_0.