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# **Resistance Oscillations Induced by a Direct Current Electromigration**

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It is found that there are three categories in small resistance oscillatory changes; typical oscillations, downward spikes and upward spikes, which are abruptly stimulated due to a direct current electromigration. Investigation on the current density dependence revealed that amplitude of the oscillation was increased with increasing the current density. It is also found that downward spikes were local, while upward spikes were non-local. It seems most likely that typical oscillations correspond to the alteration of annihilation and formation of the one void, while dislocation dynamics such as generation, rapid transport, and subsequent annihilation are strongly related to the origins of spikes.

#### 1.Introduction

Resistance change measurements during direct current (DC) test had been useful technique for measuring electromigration induced mass transport during the 1970s. Although it was indirect, the resistance change well coincides with the change in the shape of interconnections due to electromigration in those days. Recently, with the shrinkage of interconnection line width, the resistance change exhibits random fluctuations such as steps and oscillations [1]. The present work focused on the characteristics of oscillatory resistance changes which suddenly and last for some period. appear Investigations on current density dependence, as well as locality and non-locality, have been carried out.

#### 2.Results and Discussions

The test samples are Al-1%Si-0.5%Cu interconnections with multiple electrical probes formed on SiO2. Al samples were annealed at temperatures between 450 °C and 590 °C in N2 ambient after pattern delineation. During the direct current stressing test, the fluctuation of the sample voltage was amplified by the low noise amplifier (Ithaco 1201) by using AC coupling, and recorded to the data acquisition computer system. Constant current condition was set by connecting a low noise resistor with a large resistance directory to the sample.

We have found that there were three categories in the oscillatory changes : typical oscillations, downward spikes, and upward spikes (Downward means the decrease of the resistance, and upward means the

increase in the resistance). These signals suddenly appear, and continue for several minutes or up to 1 hour, and suddenly cease. Figure 1 shows the typical oscillations, and their fast Fourier transformed power spectrum. There are small fluctuations in the amplitude and frequency, however, FFT spectrum shows a clear peak at 4.2 Hz. Figure 2 shows the downward spikes and their FFT power spectrum. Amplitudes and periods are randomly distributed in most cases, and FFT spectrum indicated a broad peak which extend from 2 to 8 Hz. Figure 3 shows upward spikes. Characteristics are similar to downward spikes; amplitudes and periods are randomly distributed, and a FFT spectrum shows no There have been a few cases of periodic clear peak. downward and/or upward spikes, however, it seems difficult to classify these spikes as the typical oscillation. These resistance oscillatory changes most frequently occurred when an interconnection line width (w) was as large as a mean grain size (d), and seldom occurred for bamboo-like interconnections (d/w << 1).

We have investigated the locality and non-locality of oscillations by using interconnection patterns with multiple voltage probes. At first, the voltage between two ends of an interconnection was recorded. Once oscillatory changes appeared, voltage signals at each segment is recorded successively by changing switches. Fig.4 shows the results for the case of downward spikes. It is clearly shown that the downward spikes occurred only between the terminals 2 and 3 ; i.e., it is local. The observation for the case of upward spikes is shown in Fig.5. Upward spikes were observed in both segments between terminals 1 and 2 , and 2 and 3. From further analysis of the upward spikes, it was



Fig.1. The typical example of resistance oscillation, and its FFT power spectrum.



Fig.2. The typical example of downward steps and their FFT power spectrum.



Fig.3. The typical example of upward steps and their FFT power spectrum.

shown that the mean amplitude was strongly dependent on the line length, while the frequency was little dependent on the length. Thus upward spikes are nonlocal.

Current density dependence of the oscillatory changes was investigated by changing the current density during one duration of the oscillation, as stepwisely Arrows in Fig.6 indicate times when shown in Fig.6. the current density was increased by  $1\sim 2~\%$ stepwisely. It should be noted that the mean amplitude of the oscillation strongly dependent on the current density as shown in Fig.7, while the frequency seems not to be dependent on the current density. These behaviors are quite different from the cases of downward spikes [2]. This oscillation is somewhat special ones, since it contains apparently two processes with different relaxation times. Typical shape of this oscillation is shown in Fig.8, and the mean relaxation



Fig.5 Experiment which show non-locality of upward spikes. Upward spikes were observed in both segments between terminals 1 and 2, and 2 and 3.

time for resistance decreasing process  $\tau_1$  is 0.71sec, and that for resistance increasing process  $\tau_2$  is 2.56 sec.

It was reported that, when a void is annihilated, an enormous resistance increase occurs due to formation of a huge number of vacancies [1]. It is most likely that the typical oscillation corresponds to the alteration of the decomposition of a void into vacancies and the clustering of the vacancies to form a void.

On the other hand, upward spikes and downward spikes may relates to dislocation dynamics [3]. Stress build-up during electromigration causes formation of dislocations as a result of stress relaxation. Once dislocations are generated, they are swept away quickly due to the high current stress [4]. Thus generation, rapid transport, and annihilation at the grain boundary of dislocations may cause spikes. When the transport is as fast as several hundreds  $\mu$  m/sec due to high stress,

upward spikes would be observed. However, such dynamics of dislocations are limited within one Al grain, and they are localized. From the experimentally obtained non-local characteristics of the upward spikes, it is considered that acoustic wave pulses which accompany a significant change in stress, and resultant stress dependent resistance changes, may be origins of upward spikes.

## **CONCLUSIONS**

Small resistance oscillatory changes caused by electromigration, which are classified into three categories ; typical oscillation, downward spikes, and upward spikes, are found for the first time, and investigated in detail. Void dynamics or dislocation dynamics are considered to be origins of these oscillatory changes. It seems most likely that typical oscillations correspond to annihilation and formation of the one void. It is also found that downward spikes are local, while upward spikes are non-local. Dislocation dynamics such as generation, rapid transport, and annihilation are considered to be origins of spikes. However, it is difficult to determine which effect is dominant for each category of oscillatory changes. In-situ TEM observation is strongly required to clarify the physical origins of these phenomena.

### REFERENCES

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Fig.6 Current density dependence of the resistance oscillation. Arrows indicate the time when the current density was stepwisely changed.

Fig.8 The typical wave form of the oscillation which was sown in Fig.7.  $\tau 1$  is 0.71sec, and  $\tau 2$  is 2.56sec.