Burned Metal Phenomenon: A Study of Critical Factors and Their Effects on IC Devices during Parallel Lapping

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ABSTRACT

Parallel lapping is widely employed in destructive physical analysis on semiconductor integrated circuits, to reveal defects isolated by electrical failure analysis tools and techniques. A clean sample surface is critical so that the analysts can accurately identify the real defects and not be misled by anomalies possibly introduced during deprocessing. Burned metal has been identified as one type of failure mechanism, caused by electrically overstressing the device. Its presence as failure mechanism is usually validated by electrical and circuit analysis. However, in some cases additional burned metal was also observed on areas unrelated to suspect locations. To understand this phenomenon, we carefully examined the procedure of parallel lapping and conducted a series of experiments to determine the cause and effects of critical factors on IC devices during parallel lapping.

Keywords: IC failure analysis, parallel lapping

1 INTRODUCTION

With the continued acceleration of feature size reduction in semiconductor integrated circuits (ICs), fault isolation complexity is expected to grow exponentially. Development of novel failure analysis technologies, and perfection (and creative approaches) of the existing failure analysis techniques and tools are equally important in identifying the root cause of the failure in an accurate and timely manner [1].

IC failure analysis consists of two categories: electrical failure analysis (EFA) and physical failure analysis (PFA). The failed device is first subjected to a series of vigorous electrical tests and failure analysis techniques to isolate the defect to a suspect area. The unit is then sent to IC device analytical laboratory for deprocessing to reveal the physical anomalies at the suspect fault locations. Semiconductor deprocessing involves a number of critical chemical and mechanical procedures, and one of the most widely employed is parallel lapping. Parallel lapping is performed by mechanically polishing off one process layer at a time in order to observe physical anomalies that may be obscured by the upper process layers of the device. In any destructive physical analysis, a clean sample surface is critical so that the analysts can accurately identify the real defects, and not be misled by anomalies possibly introduced during deprocessing.

Burned metal has been identified as one type of failure mechanism, caused by electrically overstressing the device. The burned metal is usually found in the vicinity of the photon or thermal emission site, or on the signal lines connecting to the light emitting location. Electrical and circuit analyses validate and confirm the physical presence of burned metal as the cause of failure. However, in some cases additional burned metal was also observed through out the device. This raised several questions: Was the defect real? If so, why didn't the device reveal more emission sites during light emission or thermal emission microscopy analyses? Did we introduce this anomaly during parallel lapping?

To understand this burned metal phenomenon, we conducted a series of experiments focusing on parallel lapping procedures. The samples were all taken from the same wafer of graphics ICs.

2 EXPERIMENTS AND RESULTS

In a careful examination of the procedure of parallel lapping, we concluded that the varying factors were elevated temperature and the quality of water; e.g., city water versus de-ionized (DI) water. Temperature (and time duration of the samples exposed to heat) was chosen due to the fact that almost all jobs submitted for parallel lapping are packaged units, and heat must be introduced in order to extract the device from its package. Water was to be considered because of the possible high chlorine content in city water, and chlorine is known to be highly corrosive when in contact with aluminum [2] [3].

Experiment results are presented in Table 1. Temperature and time duration of the samples exposed to heat were chosen according to procedural and experimental data to successfully remove the die from its ceramic

package. The temperature is set at 526°C and the duration is 20 minutes.

Optical micrographs and Scanning Electron Microscopy (SEM) photographs in Figures 1 and 2 demonstrate the burned metal phenomena when city water was utilized during parallel lapping. Experiment II was a repeat of Experiment I to confirm the findings. Devices parallel-lapped with DI water did not reveal any burned metal. This observation was also shown on known failed devices subjected to parallel lapping with DI or city water (Experiment III).

After analyzing the results of these three experiments, we conclude that heat has no effect on the metal. However, the samples that were subjected to parallel lapping with city water revealed corroded metal. To study the effect of water during parallel lapping, we engaged Balazs Analytical Laboratory to perform the analysis of water quality. Upon receipt of the results, a fourth experiment was conducted to better understand the corrosiveness of chlorine to aluminum metal lines on ICs.

City water was not utilized in Experiment IV; however, Clorox was added to a beaker of DI water used in the rinse step after polish. Energy dispersive X-ray (EDX) analysis was performed on a sampling of Clorox to determine its elemental composition. Burned metal was observed on both samples. Chlorine and chloride percentages in the high and low concentrations of Clorox used in this experiment were 21,000 μg/g and 1,500 μg/g, respectively.

Experiment I (4 samples)

S/N	Heat	Water	Results
1	No	DI	Clean metal
2	No	City	Burned metal
3	Yes	DI	Clean metal
4	Yes	City	Burned metal

Experiment II (4 samples, repeat of Experiment I)

S/N	Heat	Water	Results
1	No	DI	Clean metal
2	No	City	Burned meta
3	Yes	DI	Clean metal
4	Yes	City	Burned metal

Experiment III (2 samples, known failed devices)

S/N	Heat	Water	Results
1	No	DI	Clean metal
2	No	City	Burned metal

Table 1: Experiments to identify critical factors during parallel lapping

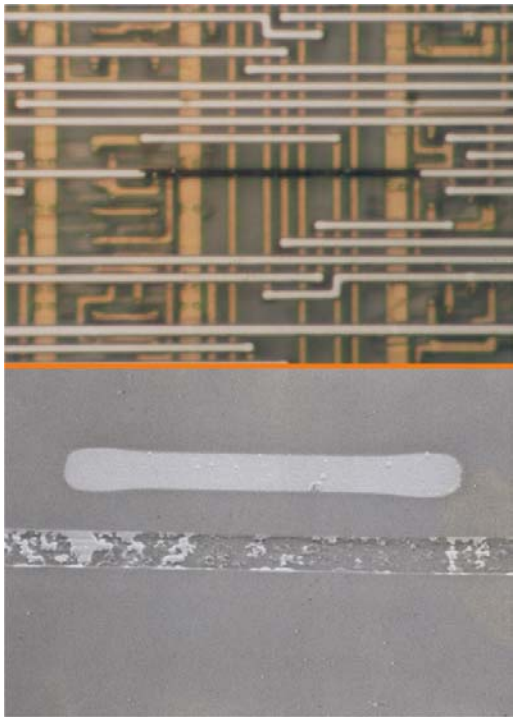

Figure 1: Optical (upper) and SEM (lower) micrograph showing burned metal. The sample was prepared at room temperature and city water was utilized in parallel lapping.

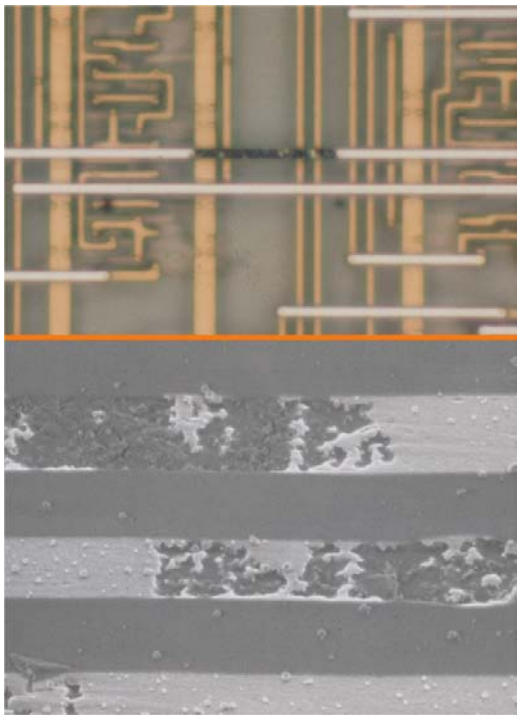

Figure 2: Optical (upper) and SEM (lower) micrograph showing burned metal. The sample was prepared at elevated temperature and city water was utilized in parallel lapping.

City Water: Concentration in *ppm* (*μg/g*)

*Analysis revealed that the ion was not found above the detection limit.

Anions	Detection limit	City Water
Fluoride (F^-)	1.0	*
Chloride (Cl^-)	0.5	70
Nitride (NO_2^-)	0.5	3.6
Phosphate ($HPO_4^=$)	1.0	*
Bromide (Br^-)	1.0	*
Nitrate (NO_3^-)	1.0	2.7
Sulfate ($SO_4^=$)	1.0	45

Di Water: Concentration in *ppb* (*ng/g*)

Anions	Detection limit	City Water
Fluoride (F^-)	2.0	*
Chloride (Cl^-)	0.02	0.10
Nitride (NO_2^-)	0.02	*
Phosphate ($HPO_4^=$)	0.02	*
Bromide (Br^-)	0.02	*
Nitrate (NO_3^-)	0.02	*
Sulfate ($SO_4^=$)	0.05	0.08

Table 2: Water laboratory results: anions by ion chromatography performed by Balazs Analytical Laboratory.

Experiment IV (2 samples)

S/N	Heat	Water	Results
1	No	DI (low Clorox)	Burned metal
2	No	DI (high Clorox)	Burned metal

Table 3: Experiments to confirm chlorine's effect on parallel lapping

3 DISCUSSION AND SUMMARY

These experiments demonstrated that additional burned metal observed on areas of the die not pertaining to emission locations was caused by the high concentration of chlorine in city water. Consultation with representatives of Balazs Analytical Laboratory indicated that a single digit reading of chlorine is enough to cause corroded metal. City water contains 70ppm, well over the limit, while DI water contains only 0.10ppb.

It must be noted that the results of the experiment do not imply that burned metal would not occur if DI water were used during parallel lapping. The burned metal witnessed in the cases correlated with electrical failure analysis techniques is known to be real and true, caused by electrical overstress of the devices. Figure 3 shows an example of burned metal resulting from electrical overstress.

The samples subjected to chlorinated DI water revealed corroded metal identical to that subjected to city water. We also observed that devices that failed for high level leakage current were more susceptible to the burned metal response to city water than normal leakage units.

Based on the experiment results and analyses, we have converted all polishing wheels to use DI water only. Hence, burned metal phenomenon on areas not confirmed and validated with electrical fault isolation procedure was no longer experienced.

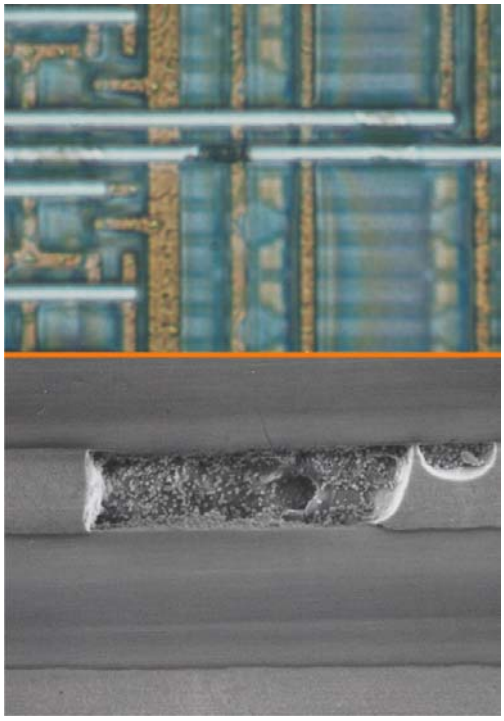

Figure 3: Optical (upper) and SEM (lower) micrograph showing burned metal resulting from electrical overstress.

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