丁燈有限公司 Excalibur 部

GPU 晶片跳電抑制方案

丁燈有限公司 Excalibur 部針對 GPU 晶片在先進制程下的跳電與線路損耗問題，提出以「低電阻材料優化 + 氮氣惰性制程環境 + 物料封存保護」三合一的改善方案。方案核心目標是降低互連線路電阻、減少氧化造成的電阻上升，從而抑制跳電、提升穩定性與晶片壽命。

材料選擇

根據常溫附近的純金屬電阻率資料，導電性最好的金屬依次為銀、銅、金、鋁、鎂；其中銀的電阻率約為 1.59×10^(-8) " " Ω·m，銅約為 1.68×10^(-8) " " Ω·m，金約為 2.44×10^(-8) " " Ω·m，鋁約為 2.65×10^(-8) " " Ω·m，鎂約為 4.45×10^(-8) " " Ω·m。由於銀雖然電阻率最低，但成本高於銅，因此本方案不建議整體改用銀，而是以銅作為主體材料，並透過石墨烯複合化降低電阻。

石墨烯銅互連

針對 1.6nm 世代 GPU 可能出現的跳電問題，Excalibur 部建議採用銅與石墨烯複合材料作為關鍵互連與導線優化方向。已有研究顯示，做得好的銅-石墨烯複合材料在室溫下，電導率可提高約 1%，即電阻大約降低約 1%；另有個別報導指出，某些石墨烯銅複合材料電阻率可降至約 1.2×10^(-8) " " Ω·m，相對純銅約 1.68×10^(-8) " " Ω·m 低約 29%。不過，較新的分析也指出，部分顯著提升可能受量測誤差影響，因此實務上應以「小幅改善可複製、大幅提升需驗證」作為技術基準。

製程控制

除了材料優化，生產環境亦是抑制跳電的重要一環。建議在相關製造線導入氮氣充填，藉由降低空氣中氧氣含量，減少銅表面氧化與氧化膜生成，從而維持較低接觸電阻與較穩定的導電表現。 同時，晶片線路完成後應加強物料封存與保護層設計，以降低外部環境對金屬互連的腐蝕與電流損耗，延長元件壽命。

安全措施

由於生產線以氮氣置換後，氧氣濃度會下降，現場人員必須配備供氧設備與氧氣監測系統，以避免缺氧風險。此項措施屬於製程安全的必要配套，不能與技術優化分開處理。

建議結論

綜合而言，Excalibur 部建議的最佳路線不是單純追求「更低 nm」或「完全取代銅」，而是以銅為基礎，透過石墨烯複合導線、氮氣惰性製程與封存保護三方面同步降低電阻與氧化損耗。若以保守估算，石墨烯複合化帶來的改善約為 1%；若製程與材料條件極佳，文獻與報導曾見到約 29% 的電阻率下降案例，但這類數據需在量產前嚴格驗證。

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Excalibur Division

GPU Chip Power-Transient Suppression Solution

The Excalibur Division of **C C LIGHT COMPANY LTD** has developed an integrated solution to address power transients and interconnect losses in GPU chips manufactured using advanced process technologies.

The proposed solution combines three key approaches:

1. **Low-resistance material optimization**
2. **Nitrogen-based inert process environments**
3. **Material encapsulation and protective-layer technologies**

The primary objective is to reduce interconnect resistance, minimize resistance increases caused by oxidation, suppress power transients, and improve chip stability and service life.

Material Selection

Based on the resistivity of pure metals at approximately room temperature, the metals with the highest electrical conductivity are generally ranked as follows:

Metal	Approximate Resistivity
Silver	$1.59 \times 10^{-8}\ \Omega \cdot \mathrm{m}$
Copper	$1.68 \times 10^{-8}\ \Omega \cdot \mathrm{m}$

Metal	Approximate Resistivity
Gold	$2.44 \times 10^{-8}\ \Omega \cdot \mathrm{m}$
Aluminium	$2.65 \times 10^{-8}\ \Omega \cdot \mathrm{m}$
Magnesium	$4.45 \times 10^{-8}\ \Omega \cdot \mathrm{m}$

Although silver offers the lowest resistivity among these metals, its cost is significantly higher than that of copper. Therefore, the proposed solution does not recommend replacing copper entirely with silver. Instead, copper should remain the primary conductor, with graphene composite technology introduced to further reduce resistance and enhance interconnect performance.

Graphene–Copper Interconnects

For potential power-transient issues in GPUs based on the 1.6 nm process generation, the Excalibur Division recommends the use of copper–graphene composite materials as a key direction for interconnect and wiring optimization.

Existing studies have indicated that well-engineered copper–graphene composites may achieve an approximately **1% increase in electrical conductivity at room temperature**, corresponding to an estimated reduction in resistance of approximately 1%.

Certain individual reports have also indicated that the resistivity of specific graphene–copper composite materials may be reduced to approximately:

$$1.2 \times 10^{-8}\ \Omega \cdot \mathrm{m}$$

Compared with the resistivity of pure copper, approximately $1.68 \times 10^{-8}\ \Omega \cdot \mathrm{m}$, this represents a reported reduction of approximately **29%**.

However, more recent analyses have suggested that some exceptionally high improvement figures may be affected by measurement uncertainty or experimental conditions. Accordingly, the recommended engineering principle is:

Modest improvements should be demonstrated for repeatability, while significant improvements must be rigorously validated.

All performance figures should therefore be confirmed through controlled testing before being considered suitable for mass production.

Process Environment Control

In addition to material optimization, the manufacturing environment is an essential factor in suppressing power transients and reducing interconnect losses.

The proposed process should incorporate nitrogen purging or nitrogen filling in relevant manufacturing areas. By reducing the oxygen concentration in the surrounding environment, this approach can help minimize copper-surface oxidation and the formation of oxide films. As a result, the process may help maintain lower contact resistance and more consistent electrical conductivity.

After the chip interconnects have been completed, enhanced material encapsulation and protective-layer designs should also be implemented. These measures can reduce the impact of environmental exposure, corrosion, and current loss, thereby supporting improved component reliability and extending operational life.

Safety Requirements

Nitrogen replacement reduces the oxygen concentration within the production environment and may create an oxygen-deficiency hazard.

Accordingly, all relevant production areas must be equipped with:

- Suitable supplied-air or oxygen-support equipment.
- Continuous oxygen monitoring systems.
- Appropriate safety procedures and emergency-response measures.

These provisions are essential process-safety requirements and must be implemented together with the proposed technical improvements. Manufacturing optimization and personnel safety must not be treated as separate considerations.

Recommended Development Path

In summary, the Excalibur Division recommends a balanced development strategy rather than simply pursuing a smaller process node or attempting to replace copper entirely.

The preferred approach is to retain copper as the fundamental interconnect material while combining:

- Graphene–copper composite conductors.
- Nitrogen-based inert process control.
- Post-process encapsulation and protective-layer technologies.

Together, these three measures are intended to reduce electrical resistance, limit oxidation-related losses, suppress power transients, improve operating stability, and extend GPU chip lifetime.

Under a conservative estimate, graphene composite integration may provide an improvement of approximately **1%**. Under highly optimized material and process conditions, certain published studies and reports have indicated resistivity reductions of approximately **29%**. Nevertheless, such significant performance figures must undergo strict verification through laboratory testing, reliability assessment, and pilot-scale manufacturing before any mass-production application.

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