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Invited

Spherical Silicon Crystal and Use for Integrated Circuits

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1. Introduction

The current semiconductor industry focuses on making integrated circuits on flat-surface wafers, with chips becoming ever more complex, wafers becoming ever larger, and the manufacturing process increasing exponentially in complexity and cost with each new generation. Instead of today's flat, rectangular chips, our idea is to make semiconductors on 1-millimeter spheres [1] that have about 3 times larger surface area than 1-millimeter square chips. And our internal goal for manufacturing cost is as low as one-tenth of the conventional semiconductor, by building the capacity by $100M against $ 1.5 billion dollars, and production lead time as short as less than a week against 100 days.

In this paper, current progress of BALL semiconductor technology [2] is summarized along the five key enabling technologies.

2. Subject

Single crystallization

The first and foremost step in making a Ball™ integrated circuit is the fabrication of single crystal spheres. Poly-crystal granules are sorted by weight and / or size to get appropriate raw material for 1-mm single crystal spheres. The granules are preheated and melted by a high-energy plasma source, Inductive Coupled Plasma (ICP). The melted granules are then dropped through a long tube for cooling. The heating and cooling rates are adjusted such that the granules become single-crystal spheres.

No-contact processing

Integrated circuit fabrication involves deposition and etching of various types of films on the ball. These typical semiconductor fabrication steps are done in clean pipes instead of a clean room. Such processing requires that the balls do not touch the walls of the pipes, or each other, to prevent damage and contamination.

The concept of no-contact transport is derived from the principles of fluid mechanics. High-speed camera pictures have shown encouraging results.

Prototype processes has been built and characterization testing of a metal-oxide semiconductor (MOS) diode and a P/N junction diode built on the surface of a sphere has begun to prove these high-temperature and floating

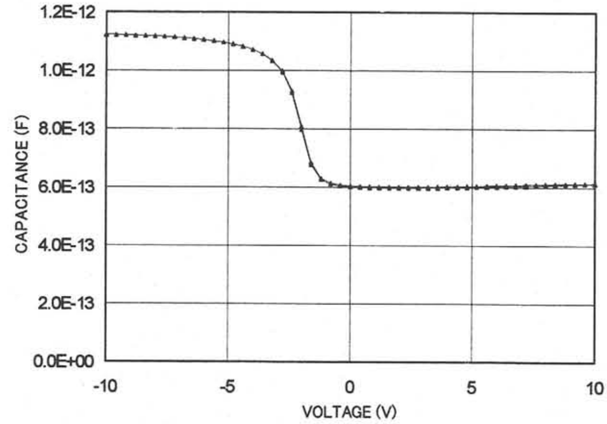

Fig.1 C-V characteristics of poly Si gate MOS diode. (oxide thickness: 70nm, oxidation temperature: 1300°C)

processes. Typical C-V characteristics of MOS diode is shown in Fig.1. Characterization testing of MOS transistors will be started soon.

Spherical lithography

One of the high hurdles in Ball Semiconductor technology is spherical lithography. We developed a system including multi faceted mirror, spherical alignment and 2D mask generation to expose the almost entire surface of a ball in one exposure shot. An optical system focuses the image of a flat mask through the mirrors onto the ball as shown in Fig. 2.

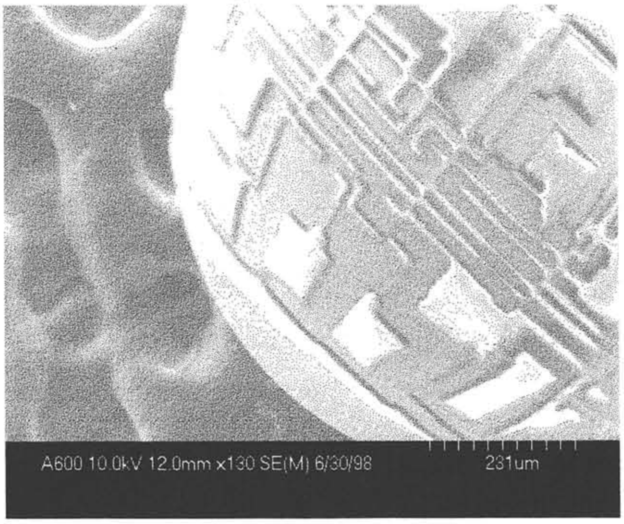

Fig. 2 SEM photograph of resist patterns on Al. (light source: g-line, resist: TOK OFPR-800, sub-fields: 15 x 3, reduction: 1/5)

3D VLSI design

Designing circuits on a sphere is another unique aspect of Ball Semiconductor technology. There are two main distinctions between a 3D design and a conventional 2D design. The first is the inability to look at the entire design surface as a whole. The second is the need to define a unit shape that can be repeated all over the sphere and provide 100% coverage without any gaps. (In a 2D world, this shape is a rectangle.)

We have developed a Lozenge Cell concept to address these issues. Currently more work is directed toward developing tools with these ideas.

VLSI by clustering

Currently large systems are built as a single VLSI circuit. The trend is to compress the functionality of many chips into a single chip. A 1-mm ball has a surface area of 3.14 sq. mm; hence, most VLSI circuits cannot be accommodated within this area. VLSI circuits are realized in Ball technology through clustering of many balls. Our approach is to produce spheres with different functions -- memory, logic, power, etc. -- in suitable processes, and then cluster the spheres needed to build a system.

3. Conclusion

The five key enabling technologies are shown here. BALL technology will enable the production of spherical (ball) semiconductors in a single, enclosed process using a manufacturing line of small tubes and pipes. BALL Semiconductor is leading a revolution in the semiconductor industry with a simple idea: a one-millimeter spherical semiconductor in place of today's flat, rectangular chip.

References

1. A. Ishikawa, USP, *pending.*
2. Proceeding of Ball Semiconductor Technology Conference, San Francisco, July 11^{th}-12^{th} (1998).