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Three-Dimensional Interconnect Technology Using Polyimide Film and Gold for MMICs

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A three-dimensional (3-D) interconnect technology using polyimide insulator film and electroplated Au was developed for ultra-compact and low-cost MMICs. The 3-D interconnect consists of vertical metal structures and a multi-leveled metal-insulator structure, all buried in a thick polyimide. These structures make it possible to place many functional passive elements and circuits in a small area on a GaAs IC or Si IC (Fig. 1). A unique inductor with a vertical structure was successfully fabricated as an example of a passive element. In addition, the resistance of the 3-D interconnect to moisture was evaluated to ascertain the feasibility of housing MMICs in inexpensive non-hermetic packages.

The fabrication process is outlined in Fig. 2. The 3-D interconnect was formed by repeating this process. The process involved three key steps: First, holes and trenches are formed in the polyimide with thickness over 2.5 μm by RIE using O_2/CF_4 gas. To eliminate etching residue, a small quantity of CF_4 gas was added to the O_2 gas. To prevent large side-etching of polyimide, we used a double-layer mask of WSi covered with a Si-containing photoresist. Second, 1-μm-thick Au metal layer was formed along the surface of the holes and trenches by low-current electroplating. By lowering the current density for plating, conformability and uniformity of the plated Au were improved. Finally, the Au metal layer plated on the polyimide surface was patterned by ion milling with the photoresist mask. To prevent Au redepositing onto the sidewall of the mask, the mask was designed to become thin and tapered at the pattern edges after ion milling. Figure 3 is an SEM image of the fabricated inductor. This unique inductor consists of four-level planar interconnects and four kinds of via connections.

The overall cost of MMICs with 3-D interconnects can further be reduced by decreasing packaging costs after IC chip size is reduced. However, with an inexpensive package, the MMICs must be extremely moisture resistant. Polyimide is very suitable as an insulator film in a 3-D interconnect because of its low dielectric constant and ease of processing to form a thick film. However, polyimide has higher moisture absorption than SiO_2 and SiN. On the other hand, Au has excellent resistance to moisture. However, Au adhesion to the insulator film is very poor. Therefore, an adhesive metal has to be inserted between them. However, the resistance to moisture of adhesive metals has not been well characterized. We therefore investigated the moisture resistance of metals (WSi/Au, WSiN/Au, W/Au, and WN/Au) using via-contact chain samples. Figure 4 shows dependence of sample failure on the metals under a relative humidity (R.H.) of 85% at 85°C with a current density of 2 x 10^5 A/cm^2. For WSi and WSiN, the number of failed samples increased after 200 h. For W and WN, there were no failures even after 1000 h. This result suggests that metal containing Si is oxidized easily. The stability of the insulating characteristics between metal lines is also important, so we investigated the leakage current between parallel lines of W/Au or WN/Au. The initial small leakage current remained in both metals under an R.H. of 85% at 85°C with a bias of 10 V for 1000 h. By employing W or WN as the adhesive metal, the 3-D interconnect using polyimide can provide sufficient resistance against moisture in non-hermetic applications.

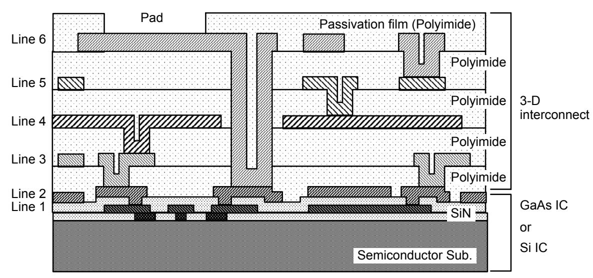

Fig. 1. 3-D interconnect structure.

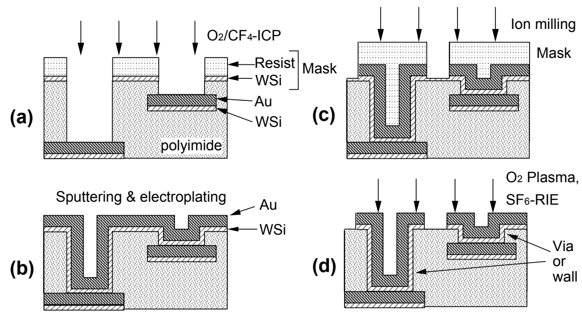

Fig. 2. Process flow.

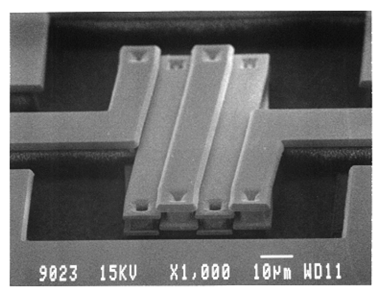

Fig. 3. SEM image of the fabricated inductor.

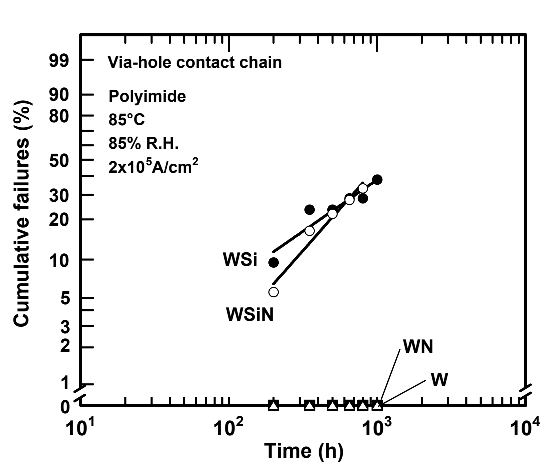

Fig. 4. Dependence of cumulative failure of via-contact chain sample on adhesive metals.