Materials, Processes, and Characterization: Insights from the Past for Advancing Interconnect Developments

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A multilayer CMOS device with laser-recrystallized Si islands was presented at the 1983 IEDM (Fig.1) (1). Polycrystalline Si and W interconnects withstood high-temperature processing (900°C), but achieving reliable ohmic contacts remained a challenge (Fig.2). Today, engineers focus on commercializing 3D-structured devices, while research on 2D material devices is also gaining momentum. However, metal-2D material contacts remain problematic (2), indicating that the issue of "contact" persists.

The Ti/Si contact interface was studied in correlation with barrier height using high-resolution microscopy (HRM) (3). A 1 nm electron probe enabled interface analysis for the first time, revealing a thin Ti-Si alloy even in the as-deposited state (Fig.3 (a), (b)). Crystallization began above 430°C, forming C49 TiSi at 460–625°C. Near the Si interface, the alloy remained amorphous but approached a $TiSi_2$-like composition, reducing the electrical barrier height around 460°C.

This new 1 nm probe also facilitated crystallinity characterization within a precise 1 nm area, aiding structural and electrical analyses of dry-etched low-k patterns (Fig.4). (4). These HRM advancements in the 1990s significantly contributed to interconnect technology development.

Helium ion microscopy (HIM), a prototype developed in 2006, has been used to manipulate the electrical properties of ultrathin 2D and superconducting materials for novel device fabrication. Graphene, now employed as a capping layer for Cu interconnects (Fig.5) (5), holds significant potential. A 0.35 nm diameter helium ion beam creates crystal defects in graphene or superconducting films—typically undesirable in semiconductors—but opens new possibilities for defect engineering.

The helium ion irradiation has been shown to transform graphene into a semiconductor or dielectric with 0.1–2% defect concentrations, enabling graphene transistors (Fig.6) (6). In h-BN films on Au wires, it generated boron vacancies with nanometer precision, which acted as quantum sensors for magnetic fields (Fig.7) (7). In YBCO superconductors, oxygen disordering induced by the irradiation converted films into metals or insulators, forming 1–2 nm width Josephson junctions (8).

HIM also enables precise graphene etching, similar to Ga FIB but with less damage, producing 18 nm-pitch nanopore arrays that induce an energy gap and control thermal transport (Fig.8) (9).

New materials, such as 2D materials and superconductors, will be integrated into 3D devices. Despite challenges, small electron probes and innovative characterization methods will overcome obstacles and advance defect-engineered processes for next-generation devices.

References

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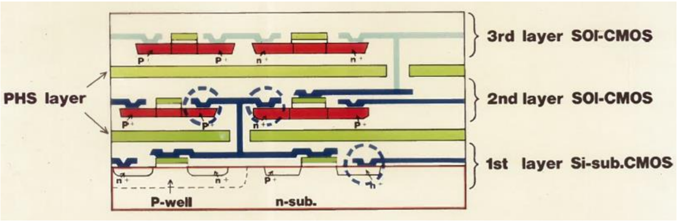

Fig. 1

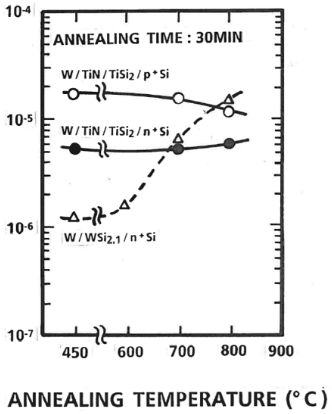

Fig.2

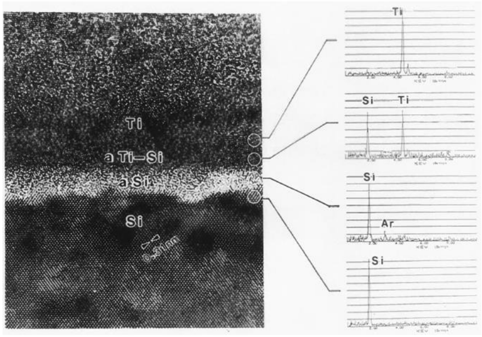

Fig. 3(a)

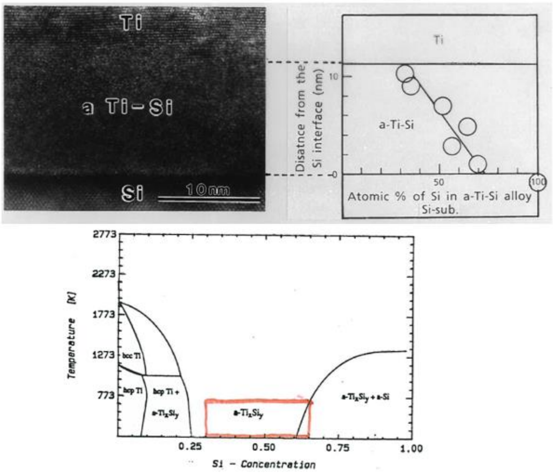

Fig. 3(b)

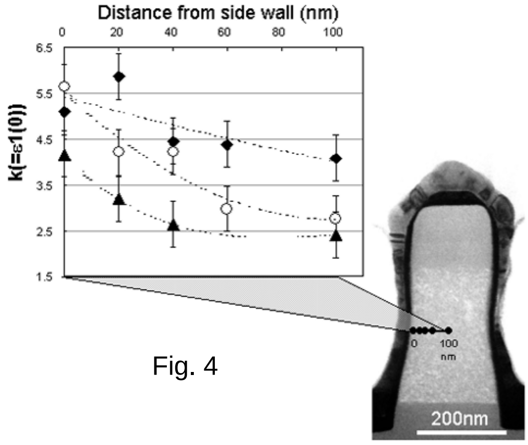

Fig. 4

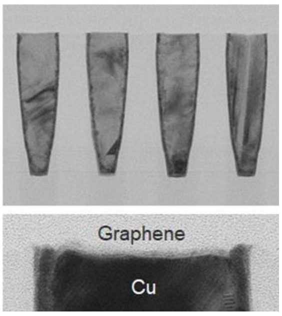

Fig. 5

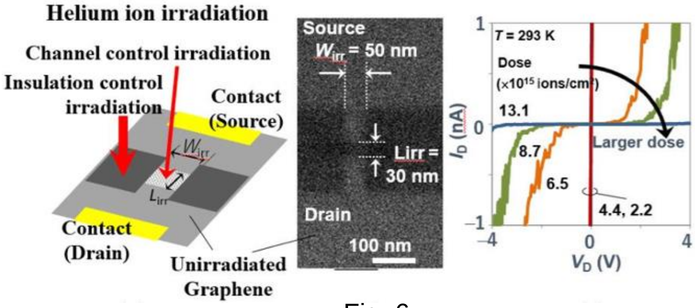

Fig. 6

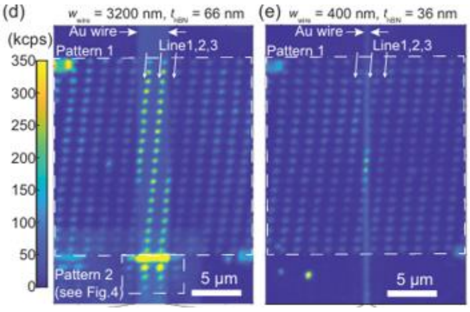

Fig.7

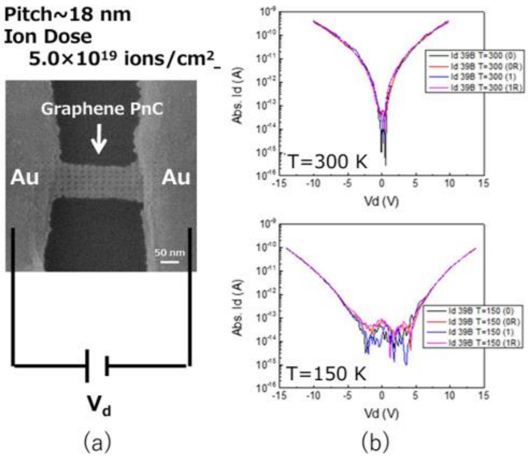

Fig. 8