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Plasma Processing for Nanoelectronics — History and Prospects[1]

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Plasma processing is a crucial technology for fabricating trillions of nanometer-size transistors on a silicon wafer [1]. It evolved from humble beginnings in the early 1900's: the silver-coating of mirrors by physical sputtering in dc glow discharges. The late 1950's - early 1960's saw extensive studies of physical and reactive sputtering in capacitive rf reactors. Isotropic plasma etching, mainly for photoresist stripping, was developed in the late 1960's - early 1970's, and etching of many other important materials was demonstrated. Three key advances in the late 1970's made plasma processing technology indispensable: (a) the discovery of ion-enhanced (anisotropic) etching [2]; (b) the development of SiO_2 etching with high SiO_2/Si selectivity [3]; and (c) the controlled etching of passivating films, eg, Al_2O_3 over Al [4]. As scale-down to current 32 nm (100 atom) transistor gate lengths proceeded, etching discharges evolved from a first generation of "low density" reactors capacitively driven by a single source, to a second generation of "high density" reactors (inductive and electron cyclotron resonance) having two power sources, in order to control independently the ion flux and ion bombarding energy to the substrate. A third generation of "moderate density" reactors, driven capacitively by multiple frequency sources, is now used to further control processing characteristics, such as ion energy distributions, uniformity, and selectivity. There is yet much to be understood, e.g., the physics of multiple-frequency sheaths, nonlinear frequency interactions, and electromagnetic effects such as standing waves. Beyond the 6–11 nm transistor limit lies a decade of further improvements for conventional nanoelectronics, and beyond that, a dimly-seen future of spintronics, single-electron transistors, cross-bar latches, and molecular electronics.

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[4] S.I.J. Ingrey, H.J. Nentwich, and R.G. Poulsen, "Gaseous Plasma Etching of Al and Al2O3," USP 4,030,967 (filed 1976).

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