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Atomic Layer Processing of Oxides: Area-Selective ALD and Selective ALE of ZnO

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Atomic Layer Deposition (ALD) and Atomic Layer Etching (ALE) provide Ångström-level film thickness control. Here, we focus on Area-Selective ALD (AS-ALD) and ALE of ZnO processed at 100-250°C. AS-ALD of ZnO was done on SiO_2 seed layer patterns on H-terminated Si substrates from diethylzinc and H_2O as reagents. *In-situ* spectroscopic ellipsometry and SEM/TEM electron microscopy with EDX revealed improved selectivity at higher deposition temperatures. By combining the experimental results with Density Functional Theory, we conclude that the trend in selectivity with temperature is due to a strong DEZ or H_2O physisorption on the H-terminated Si at low deposition temperature. This makes temperature a process parameter to improve selectivity. Recent ALE research has focused on 1) Ion-driven plasma etching yielding anisotropic (=directional) etch profiles 2) Thermally-driven etching for isotropic material removal. Here, we will show that one can also obtain isotropic etch profiles in plasma-based ALE of ZnO, which is radical-driven and utilizes acetylacetone (Hacac) and O_2 plasma as reagents. *In-situ* ellipsometry revealed self-limiting half-reactions with etch rates of 0.5-1.3 Å/cycle at 100-250°C. The process was shown on planar and on 3D substrates made up by a regular semiconductor nanowire forest conformally covered by ALD-grown ZnO. TEM studies on these nanowires before and after ALE showed the isotropic nature and the damage-free characteristics of the process. *In-situ* infrared spectroscopy was used to study the self-limiting nature of the ALE half-reactions and the reaction mechanism. During the Hacac etch reaction that produces $Zn(acac)_2$, acac-species adsorbed on the ZnO surface are the probable cause of the self-limition. The subsequent O_2 plasma step resets the surface for the next ALE cycle. High etch selectivities (~80:1) over SiO_2 and HfO_2 were demonstrated. Preliminary results indicate that this process can be extended to other oxides such as Al_2O_3.

Biography:

Prof. Fred Roozeboom after his MSc from Utrecht University and PhD at Twente University, Netherlands. From 1980-1982 Fred Roozeboom continued his career in catalysis with ExxonMobil in Baton Rouge, USA. In 1983, he joined Philips Research (since 2006: NXP) in Eindhoven to work on thin-film technology for III-V and Si semiconductors and soft-magnetic materials. From 1997-2009 he led a team on 3D passive Si-integration. For this work he received the Bronze Award for '*NXP Invention of the Year 2007*' and became NXP Research Fellow.

In 2007 he became part-time professor at TU Eindhoven. In 2009 he joined a team at TNO Eindhoven specializing in spatial ALD and ALE. In 2014 he became Fellow of the Electrochemical Society. Fred is co-author of 200+ publications (h-index: 33), 5 book chapters, 35 granted US patents and co-editor of 41 conference proceedings on semiconductor processing.

Fred has been or is active in organizing committees of several conferences (Materials Research Society, Electrochemical Society), was an MRS Meeting chair in 2003 and is a member of the SEMI Europe Semiconductor Technology Programs Committee.

His topics of interest are ultrathin-film technology, plasma processing, reactive ion etching, (spatial) atomic layer processing, 3D passive and heterogeneous integration, RTP, microsystem technology, Li-ion micro-batteries, sensors, displays and EUV optics lifetime.