

ALD Fundamentals

Room Hall 3F - Session AF3-WeA

Growth and Characterization: Plasma Enhanced ALD II

Moderators: **Matti Putkonen**, University of Helsinki, **Mikko Söderlund**, Beneq Oy

4:00pm AF3-WeA-11 UHP PEALD Growth and High Field Dielectric Testing of κ -Ga₂O₃ Films, **Bangzhi Liu**, The Pennsylvania State University

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Ga₂O₃ has multiple different polymorphs: α -, β -, γ -, and ϵ (κ)-phases. β -Ga₂O₃ has drawn significant attention in the power electronics community since it is an ultra-wide bandgap semiconductor and, fortunately, the only thermodynamically stable phase. The ϵ (also called κ)-phase is the next most stable polymorph. This metastable phase has been predicted to be ferroelectric^{1,2} and can be a suitable candidate for non-volatile memory applications if its ferroelectricity is confirmed. Technically, using ALD to grow this film is ideal for memory device fabrication, given its precise thickness control and excellent conformality.

To this end, we invested significant effort in developing a Plasma-Enhanced ALD (PEALD) process to grow κ -phase with c -orientation on a conductive substrate for electrical testing. The deposition system used was a KJ Lesker ALD150LX operating under ultrahigh purity (UHP) conditions. A major challenge was to find conditions that favor the formation of metastable κ -phase while suppressing the growth of stable β -phase. By controlling O₂ flow, vacuum level, plasma power, growth temperature and substrate type, we successfully grew c -oriented κ -phase (50 nm thick) on platinumized sapphire substrates. The films were characterized by ellipsometry, FESEM, XRD, and ToF SIMS for material properties and by high field dielectric testing and Piezoresponse force microscopy for the possible ferroelectric properties. A comparison was made to Metal-Organic Chemical Vapor Deposition (MOCVD) grown thick films (700 nm) with predominantly the κ -phase prepared by our collaborators in parallel to better evaluate the ferroelectricity of κ -Ga₂O₃³.

4:15pm AF3-WeA-12 Crystalline Phase Control of Manganese Oxide Films by Plasma Enhanced Atomic Layer Deposition, **Zhongwei Liu**, *J. Ren, H. Fang, L. Sang*, Beijing Institute of Graphic Communication, China

Over the past decades, manganese oxides have attracted increasing interests due to their various compositions, such as MnO, Mn₂O₃, MnO₂, Mn₃O₄, and Mn₅O₈, in which several oxidation states, +2, +3, and +4 exist. The multitude of structures and valence state offer a number of applications for manganese oxides in catalysis, microelectronic, biosensors, and Li ion battery. In this work, we developed a plasma enhanced pulsed chemical vapor deposition process for manganese oxide (MnOx) thin films using bis(1,4-di-tert-butyl-1,3-diazabutadienyl)manganese(II) (Mn(dad)₂) as the Mn precursor. Mn(dad)₂ is an active compound with high volatility, and suitable for CVD or ALD process. MnOx film was characterized by X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), scanning electron microscopy (SEM) (FEI Talos F200S). The effects of the deposition temperature and the types gases, such as H₂, Ar, H₂ plasma and Ar plasma, on phase composition of manganese oxides were carefully investigated. When Ar or H₂ gas was employed as the discharge gas and the deposition temperature was 120 °C, amorphous or nanocrystalline MnOx was obtained. In contrast, the film grown in Ar plasma was a face-centered cubic (fcc) MnO structure. In the case of H₂ plasma, the diffraction peaks can also be indexed to fcc MnO, except that the preferred orientation of the film was different. As the deposition temperature was increased to 180 °C, the film deposited in Ar or H₂ gas showed Mn₃O₄ structure. Similar to that grown at 120 °C, the film deposited at 180 °C in Ar or H₂ plasma was identified to be MnO, indicating that the deposition temperature has negligible effect on the film crystallinity under plasma condition. If the deposition temperature was further raised to 240 °C, a mixture MnO and Mn₃O₄ was obtained for the films grown in Ar or H₂ gas, while in the case of Ar or H₂ plasma, the afforded film is still MnO. These results indicated that the plasma had a significant effect on MOx crystalline phase.

Wednesday Afternoon, August 7, 2024

4:30pm AF3-WeA-13 Superconducting Ultrathin Niobium Nitride Films for Quantum Application, **Mario Ziegler**, *E. Knehr, E. Mutsenik, S. Linzen, G. Oeslner, E. Il'ichev, R. Stolz*, Leibniz Inst. of Photonic Technology, Germany

Superconducting thin films are the basis for a wide range of applications such as quantum cryptography, sensing, quantum metrology or quantum computing. On one hand, devices such as superconducting nanowire single photon detectors (SNSPDs) are in need for high-quality films with high critical temperatures (T_c) [1]. Especially in transition from single- to multi-pixel devices, the properties have to be uniform over a large surface area. On the other hand, novel concepts of second generation quantum devices such as charge quantum interference devices based on coherent quantum phase slip require disordered superconductors with high kinetic inductance [2,3]. NbN is a promising candidate as the T_c (bulk T_c=16 K) in comparison to TiN, TaN, MoSi or WSi allows for higher operating temperatures, higher switching currents, and thus a better signal-to-noise ratio. Nevertheless, the variety of applications demands for a flexible and adaptable manufacturing process with very good control of the thin-film properties, ideally over a larger surface area.

In this context, plasma-enhanced atomic layer deposition (PE-ALD) exhibits very good thickness homogeneity over a broad surface area as well as a nearly perfect thickness control. But when it comes to quantum applications, homogeneity is not only determined by roughness and layer thickness. Also, electrical properties such as normal sheet resistance, critical temperature, or critical current density must be considered. Up to now, PE-ALD processed NbN achieved T_c of 14 K for a 21 nm thick film [4] and even films with 2.7 nm thickness are still superconductive [2]. NbN films made by PE-ALD revealed a complex chemical composition not only consisting of stoichiometric NbN but also of niobium carbide, niobium oxide, and niobium-oxynitride. We observed that the electrical properties changed drastically, whereas film thickness and roughness remained almost constant. The deviations might originate from the reactor geometry or fluctuations of precursor supply during the deposition process. We will present optimized fabrication recipes for SNSPDs with high T_c as well as for circuits of highly disordered superconducting materials [2,3,5].

References

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2. Shaikhaidarov et al., Nature 608, 45 (2022).
3. De Graaf et al., Nature Phys 14, 590 (2018).
4. Ziegler et al., IEEE Trans. Appl. Supercond. 27, 1 (2017).
5. Mutsenik et al., Low Temperature Physics 49, 92 (2023).

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