Exotic combination of optical and mechanical properties of nanoparticle composite thin films fabricated by plasma processes

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Abstract: Nucleation is a crucial step of thin film formation. We discuss three kinds of nucleation: nucleation in gas phase, nucleation on substrates, and nucleation under catalyst. By utilizing nucleation in gas phase, we obtained nanoparticle composite films having exotic combination of optical and mechanical properties. Regarding nucleation on substrates, we have developed “inverse SK mode deposition” which is a new mode of hetero-epitaxial film growth. As a novel thin film formation method using nucleation under catalyst, we have developed “sputtering assisted metal-induced layer exchange”.

Keywords: plasma CVD, nanoparticle composite film, hetero-epitaxy, inverse SK mode, layer exchange, sputtering, ZnInON

1. Introduction

Nucleation is the first and probably the most important step in achieving good quality films. Nucleation is classifies into homogenous one and heterogeneous one. In most thin film formation, heterogeneous nucleation, namely nucleation on substrates is predominant one. Although little attention has been given to other types of nucleation so far, homogenous nucleation and another type of heterogeneous nucleation, that is, nucleation under catalyst can play important roles in thin film formation. Here we discuss these three kinds of nucleation and show how to tune film properties by controlling the three kinds of nucleation.

2. Nanoparticle composite films

We applied multi-hollow discharge plasma CVD (MHDPCVD) reactor [1-9] to deposit films with and without nanoparticles. Plasmas were generated in the holes of the electrodes. Nanoparticles nucleated and grown in the plasmas were transported to the substrate via gas viscous force. Therefore, nanoparticle composite films are deposited in the downstream region, whereas films without nanoparticles are deposited in the upstream region. We can compare properties of these two kinds of films.

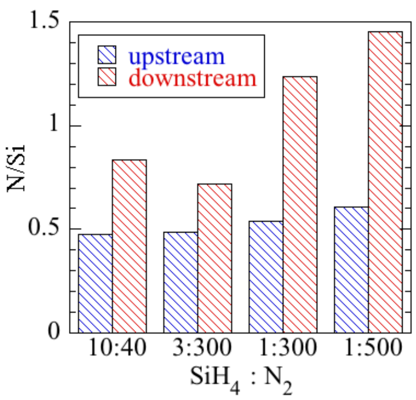

Fig. 1. N/Si of upstream and downstream films.

Figure 1 shows comparison of atomic composition ratio, N/Si of amorphous SiN_x films deposited at 100 °C in the upstream region and in the downstream region. The ratio of upstream films stays constant irrespective of gas flow ratio, whereas the ratio of downstream films tends to increase with N_2 flow rate. The results clearly demonstrate that the nanoparticle incorporation amount is one of the tuning knobs of the properties of films.

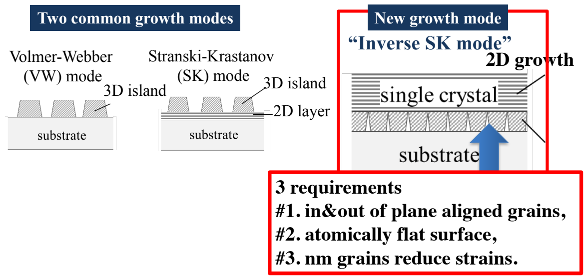

Fig. 2. Schematic of inverse SK mode as well as VW and SK modes.

3. Inverse SK mode

The inverse SK mode in Fig. 2 is a new mode of hetero-epitaxial film growth, in which stress is relaxed in an atomically flat buffer layer consisted of nanocrystals aligned in-plane and out-of-plane and single crystal with a low defect density grows on the buffer layer [10-20]. To realize the buffer layer of this mode, we applied impurity-mediated sputtering. Nitrogen was employed as an impurity for ZnO and ZnInON film fabrication. We obtained single crystal ZnO on sapphire with a large lattice mismatch of 18%. The inverse SK mode opens great possibilities of single crystal hetero-epitaxy of multicomponent systems with a wide mixture range. The impurity-mediated sputtering provides an alternative method for amorphous film formation at rather high deposition temperature. We applied this method to obtain amorphous ITO films with a high mobility.

4. Sputtering assisted metal-induced layer exchange

The metal-induced layer exchange is a well-known method of crystal film formation on glass and polymer. We reduced the processing time by 2-3 orders of magnitude and the processing temperature using a sputtering-assisted metal-induced layer exchange method as shown in Fig. 3 [21, 22]. By applying the method, we succeeded in crystalline Ge formation on polyamide films at 150-170 °C in a short processing time of 10 min.

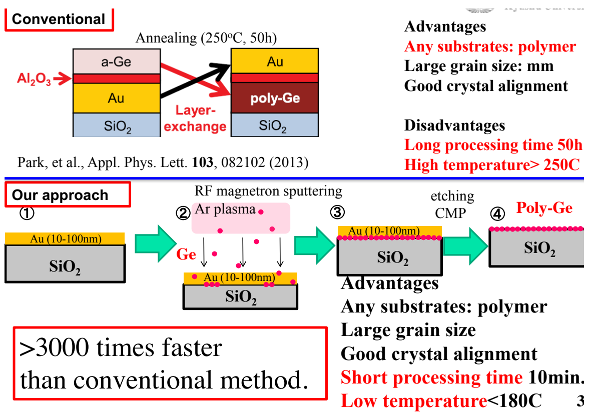

Fig. 3. Schematic of sputtering assisted metal-induced layer exchange.

5. Acknowledgements

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6. References

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