UNIVERSITÄT DUISBURG ESSEN

Open-Minded

A European Training Network TERA OPTICS

Structural, optical, and mechanical properties of silicon nitride films deposited by inductively coupled plasma enhanced chemical vapor deposition

Ezgi Abacıoğlu and Andreas Stöhr

University of Duisburg-Essen, ZHO / Optoelectronics, Duisburg, Germany

Abstract

Silicon nitride (SiN_x) is a widely used dielectric material due to its superior optical properties and compatibility with processing techniques of semiconductor and microelectronics devices. Other than its potential applications, this material is regarded as a hard-mask material for patterning of such devices [1, 2] and as an alternative to traditional doped silica waveguide technology in indium phosphide-based photonic integrated circuits (InP PICs) [3]. In the context of the required SiN_x film thicknesses, which are generally greater than 1 µm for dry etching, the mechanical stress within these films can make processing steps such as photolithography extremely challenging along with affecting the integrity and performance of the PICs. In this study, a low-temperature and low-pressure SiN_x film deposition on InP substrates is investigated using inductively coupled plasma enhanced chemical vapor deposition (ICPECVD) technology. We discuss herein the effects of structural and mechanical properties of the ICPECVD-SiN_x films on dry etching process.

ICPECVD-SiN_x Films

We deposit SiN_x films as hard-mask material using ICPECVD for patterning our UTC-PDs via subsequent dry etching process. ICPECVD offers following advantages:

- low-temperature and low-pressure deposition to avoid effects such as diffusion, phase transformation, and photoresist decomposition
- tunable deposition rates as well as high-quality products with excellent conformality

The SiN_x films are deposited on InP wafer for structural and optical characterization. The results are shown in Figure 1 and Figure 2.

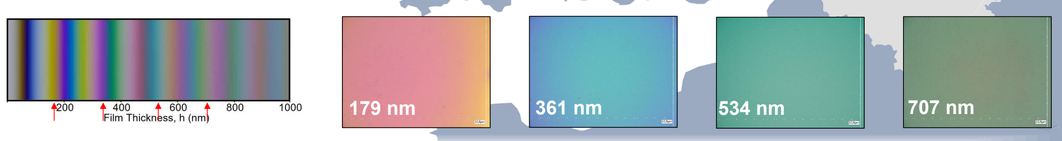

Figure 1. Characterization of ICPECVD-SiN_x thin films deposited at 130 °C for different process durations through color chart

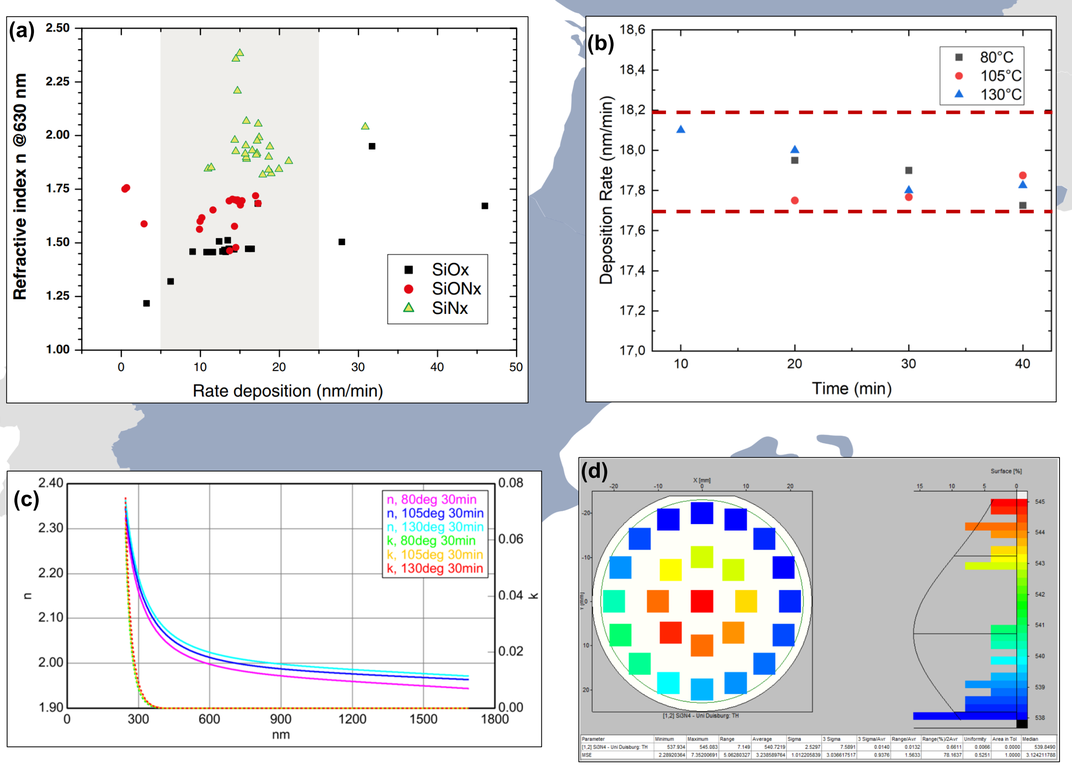

Figure 2. a) Refractive index @ 630 nm vs. deposition rate of ICPECVD-SiN_x thin films from Ref. 4, b) and c) deposition rate and *n-k* plots of our ICPECVD-SiN_x thin films deposited at different temperature and process durations, and d) mapping of our ICPECVD-SiN_x thin films deposited on 2" InP wafer at 130 °C for 30 min

Mechanical Stress in SiN_x Films

Low stress SiN_x films are required in order to achieve the succeeding photolithography step without integrity problems. High mechanical stress in the films results in:

- poor adhesion of SiN_x thin films on InP substrate
- lift-off in PR development step with increased SiN_x film thicknesses

Table 1. ICPECVD process parameters, resultant SiN_x thin film thickness values, and adhesion behavior of SiN_x thin films on InP substrate

ICP_{coil} (W)	Temperature (°C)	Pressure (Pa)	Time (min)	Thickness (nm)	PR Development Step
500	130	10	10	179	No lift-off
500	130	10	20	361	Lift-off
500	130	10	30	534	Lift-off

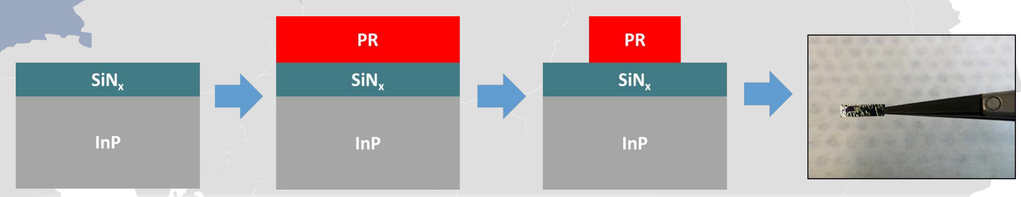

Figure 3. Photolithography steps and poor adhesion of a high stress SiN_x film on InP substrate

Stress Measurements

The measurements were conducted using a stylus profilometer.

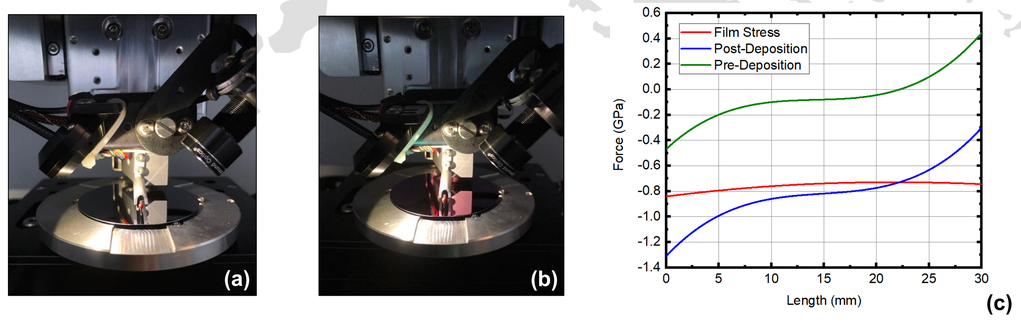

Figure 4. Pictures of stress measurements on bare Si wafer (pre-deposition) in a) and after SiN_x deposition on the wafer (post-deposition) in b). The results of the stress measurements are illustrated in c) revealing an average compressive stress of 0.76 GPa

References

[1] V. Jovanović et al., "Sub-100 nm silicon-nitride hard-mask for high aspect-ratio silicon fins", Proceedings of the International Convention MIPRO (2007).

[2] J. Haneveld et al., "Nano-ridge fabrication by local oxidation of silicon edges with silicon nitride as a mask", Journal of Micromechanics and Microengineering (2016) 16 S24.

[3] J. Klamkin et al., "Indium Phosphide Photonic Integrated Circuits: Technology and Applications", IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (2018) pp. 8-13.

[4] Herth et al., International Journal of Precision Engineering and Manufacturing-Green Technology (2021).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 956857.