Optical Characterization of an Amorphous-hydrogenated Carbon Film and its Application in Lithographic Masks

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Abstract

Considering that for IC fabrication there are up to a dozen process steps and the alignment of lithographic masks is time expensive, a material that is transparent at the visible region, while been opaque at the optical lithography wavelength, would considerably reduce this time. Among its broad spectrum of applications, amorphous hydrogenated carbon (a-C:H) matches this property. In this work we present an optical characterization of a-C:H, which is necessary to determine a suitable process window for the optical exposure. From those investigation we have obtained a carbon lithographic mask capable to operate at 365 and 248 nm wave lengths. Test structures were patterned onto silicon substrate using the proposed mask and good results were obtained.

1. Introduction

The number of applications for amorphous hydrogenated carbon (a-C:H) thin film, often called a Diamond Like Carbon (DLC) has increased considerably in the last years. One can find this type of material acting as a protective coating against chemically harsh environments [1]; as a protective coating in order to reduce abrasive effects between metallic parts [2]; in the field of microelectronics, carbon films are used as positive-acting resist in DUV microlithography in order to transfer fine features into silicon and InP [3]; it is also possible to manufacture waveguides in amorphous carbon by manipulating the chemistry of the process during the deposition in order to vary the refractive index of the film [4].

In this work, such a carbon film was used as active part of an amplitude lithographic mask.

2. Deposition of the a-C:H layer

For the manufacturing of the mask, a three inch diameter, high transparency, optical quality fused silica substrate with a refractive index of approximately 1.45 (Valley Design: www.valeydesign.com) serves as a mechanical support for the active parts of the device. On this substrate a a-C:H layer was deposited by reactive magnetron sputter in a home made system. A methane plasma was created to sputter a graphite target and deposited a hydrogenated carbon film on the fused silica substrate. Distance between graphite target and glass substrate was 10 cm, what resulted in a deposition rate of 13 nm/min, measured by ellipsometry (Auto EL NIR 3, Rudolph Research). Varying the processing times up to 150 minutes yielded films with different thickness up to 2000 nm.

The deposition process as well as its mechanical, electrical and chemical characteristics of the resulted films are described in detail in [5]

3. Determination of the absorption coefficient of the a-C-H layer

The absorption coefficient of the a-C:H deposited on a fused silica substrate was determined employing UV-VIS-NIR spectrometric technique. The equipment used for these experiments was a Varian, model Cary 500. The technique consists in measuring the intensity of the transmitted light as a function of wavelength. Figure 1 shows transmittance curve for a-C:H for four different thickness, deposited on top of a three-inch diameter fused silica substrate. From those curves one can observe that a film thickness of 2000 nm is suitable to be used in a lithographic mask operating at 365 nm wavelength (as well as 248 nm). Concerning the transmittance curve of a 2000 nm-thick a-C:H layer, the Lambert-Beer law [6] can be applied, enabling the determination of the absorption coefficient of the film as a function of the wavelength. Figure 2 shows a plot of the absorption coefficient of a 2000 nm-thick a-C:H layer. The values of this parameter are 2.4 10^{-3}nm^{-1} at 365 nm, and 7.7 10^{-5} nm^{-1} at the visible

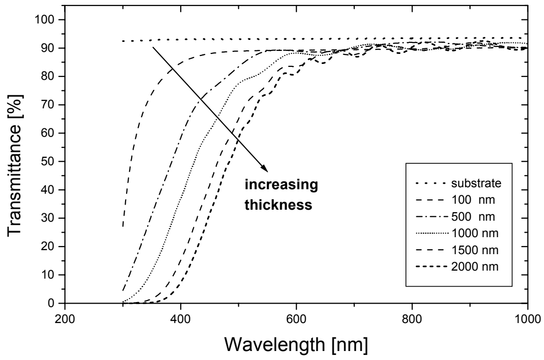

Fig.1- Transmittance curves of a-C:H thin films with four different thickness.

region. This low value for the absorption coefficient at the visible region turns possible easy alignment procedure between two lithographic steps, during an IC manufacturing.

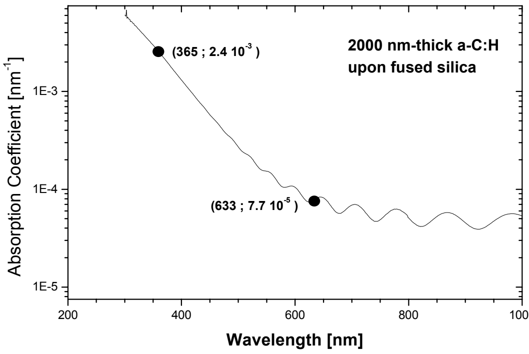

Fig. 2- Absorption coefficient of a 2000 nm-thick a-C:H layer.

4. Fabrication of the a-C:H lithographic mask and obtained results

After sputter deposition of a 2000 nm thick a-C:H layer on a fused silica wafer (three inch diameter, 0.5 mm thick), test structures was patterned on the carbon layer. A 1.2 µm thick, positive photoresist was spun on the wafer, followed by a soft bake step (during 90 seconds at 105 Celsius), exposed by UV light during 12 seconds (at 25 mW/cm^2), developed and hard baked (during 5 minutes at 115 Celsius). Then the amorphous carbon layer was etched in oxygen plasma, in a single wafer Reactive Ion Etching (RIE) system [7]. The process conditions were 50 mTorr pressure, 100 W rf-power (resulting in a cathode self-bias of approximately 560V). The etch rate was 300±2% nm/min The remaining photoresist was then stripped away in an acetone bath, which didn’t affect the amorphous carbon layer.

Once the mask was fabricated, it was used to pattern the test structures on a silicon wafer. For this end, a photoresist film was spun and pre-baked in the same way as above explained. The exposure was made at 365 nm, during 16 minutes (at 0.2 mW/cm^2) in contact mode, followed by development and post-bake. Figure 3 shows a panoramic SEM picture of the resulted structures on top of a silicon wafer. All the structures was transferred successfully to the silicon surface, proving the feasibility of the method.

5. Conclusions

In this work, a hydrogenated amorphous carbon (a-C:H) thin film was used to implement an amplitude lithographic mask.

Films of several thickness was deposited in order to determine the adequate thickness for a mask operation on 365 and 248 nm wavelengths as well.

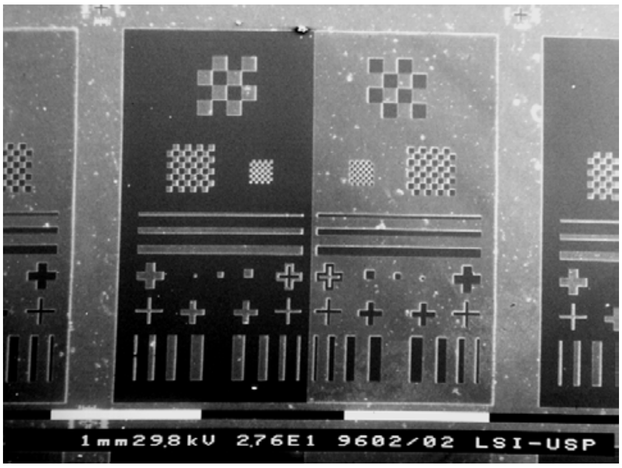

Fig.3 - Panoramic SEM picture of the resulted structures on top of a silicon wafer

A 2000 nm thick carbon layer presented the best result. The absorption coefficient of the carbon film was determined by UV-Vis-NIR spectrofotometry technique, as a function of the wavelength. Test structures was then patterned onto silicon wafer and good results was obtained.

6. Acknowledgements

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