Deposition and characterization of amorphous hydrogenated diamond-like carbon films (a-C:H)

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1 Introduction

State of the art passivation layers (SiO_2 and its modifications) are reaching their limits at high voltage and high electric fields. DLC (diamond-like carbon) has suitable mechanical and chemical properties. Because of the high density of states in the band gap, mirror charges can be created, which avoid high electrical field peaks, and which are able to compensate disturbing interface charges. This results in high breakdown voltage and excellent long term stability and reliability [1].

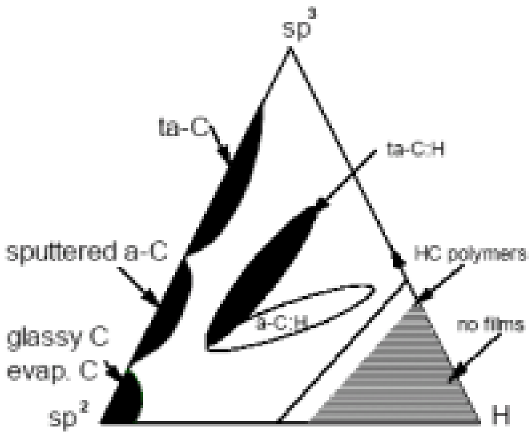

Fig. 1. Phase diagram showing composition of a-C:H, ta-C and ta-C:H [3]

2 Diamond-like carbon

Carbon forms a great variety of crystalline and disordered structures because it is able to exist in three different hybridisations, sp³, sp² und sp^1 [2]. In diamond carbon's four valence electrons are each assigned to a tetrahedrally directed sp³-orbital. The sp² configuration characterizes a graphitic structure. DLC is a metastable form of amorphous carbon containing a significant fraction of sp³ bonds. The term a-C:H as an abbreviation for amorphous, hydrogenated carbon describes a system which covers a wide range of properities depending on deposition parameters. A rough classification of a-C:H films is given by the fractions of hybridisation type and hydrogen contend. Hydrogen rich films with a hydrogen contend of 40% or more , commonly deposited with low ion energies, are often so called polymerlike a-C:H films, whereas dense, sp³ rich a-C:H films with a hydrogen fraction lower than 30% are called diamond-like carbon (DLC). This notation should not mislead. There is no 3D network of tetrahedrally bonded sp³ carbon incorporated in these films but an amorphous network of graphitic clusters interconnected by sp³bonds.

	sp³ (%)	H (%)	Density (g cm^{-3})	Band Gap (eV)	Hardness (GPa)
Diamond	100	0	3.515	5.5	100
Graphite	0	0	2.267	0	
C_{60}		0		1.6	
Glassy C	0	0	1.3-1.55	0.01	3
Evaporated C	0	0	1.9	0.4-0.7	3
Sputtered C	5	0	2.2	0.5	
ta-C	80-88	0	3.1	2.5	80
a-C:H hard	40	30-40	1.6-2.2	1.1-1.7	10-20
a-C:H soft	60	40-50	1.2-1.6	1.7-4	<10
ta-C:H	70	30	2.4	2.0-2.5	50
Polyethylene	100	67	0.92	6	0.01

Table 1: Comparison of properties of amorphous carbon with reference materials diamond, graphite, C_{60} and polyethylene

3. Deposition

It is possible to produce DLCs with various deposition methods such as mass selected ion beam deposition (MSIB), sputtering of a graphite electrode by Ar plasma, filtered cathodic vacuum arc (FCVA) or plasma enhanced chemical vapour deposition (PECVD).
At the TU-Chemnitz DLC films will be deposited with a Roth&Rau MicroSys 500 PECVD system. It consists in a adjustable parallel plate arrangement within a chamber of 500 mm in diameter, a water cooled substrate electrode for deposition dimensions up to 300 mm in diameter, a 5 kW rf generator and a gas supply system for 4 gas lines. To control the plasma energy the generator runs either on fixed rf power or on fixed dc bias voltage. The system is suitable for deposition and for structuring of DLC-films. The DLC etching process development has been scope of former investigations.
Different forms of the PECVD technique constitute the main methods for depositing hydrogenated DLC films. Any hydrocarbon with sufficient vapour pressure can in principle be used as source material for the PECVD of DLC films. Among these are acetylene, benzene, butane, cyclohexane, ethane, ethylene, hexane, isopropane, methane, pentane, propane and propylene.

4 Characterization

A variety of techniques have been used to estimate sp^3/sp^2 ratio. Transmission electron microscopy (TEM) is suitable to investigate the interface between substrate and a-C:H. Fig. 2 shows a TEM picture of the Si/DLC interface.
The material properties of amorphous hydrogenated carbon films deposited by plasma chemical vapor deposition from seven different saturated and unsaturated hydrocarbon source gases were investigated in [4]. It was shown that the precursor gas substantially influences the film properties. The unsaturated hydrocarbons acetylene and ethylene lead to films with higher density, lower hydrogen content, and higher refractive index than saturated hydrocarbons. This holds for low and high ion energies.
Fig. 3 shows the influence of different hydrocarbons to the optical transmission of DLC film. Deposition has been performed at the same pressure, gas flux and self bias voltage. To retain self bias at 750 V, only 73 % of the rf generator power level was necessary for acetylene compared to methane. The methane (CH_4) based film shows a slightly darker surface than acetylene (C_2H_2) based, this can be explained by its more graphitic like film composition. Acetylene's deposition rate was five times as much as the one of methane due to acetylene's two carbon atoms and due to less sputter effect of the Ar carrier gas.

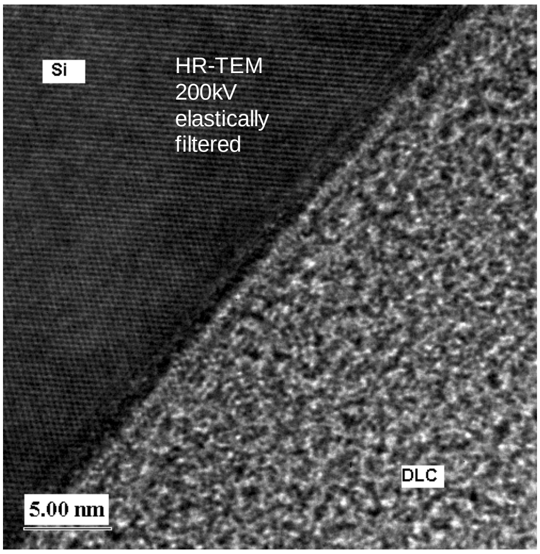

Fig 2: TEM-Picture of the interface Si/DLC

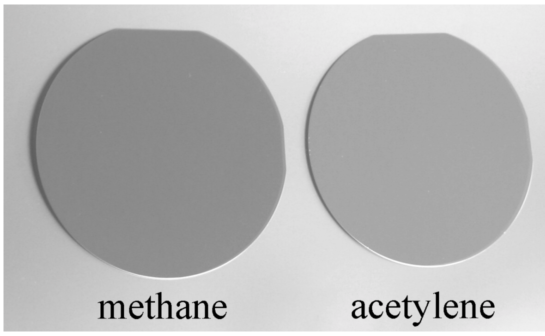

Fig. 3. Influence of hydrocarbons

References

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