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High rate deposition of ta-C:H using an electron cyclotron wave resonance plasma source

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Abstract

A compact electron cyclotron wave resonance (ECWR) source has been developed for the high rate deposition of hydrogenated tetrahedral amorphous carbon (ta-C:H). The ECWR provides growth rates of up to 1.5 nm/s over a 4-inch diameter and an independent control of the deposition rate and ion energy. The ta-C:H was deposited using acetylene as the source gas and was characterized as having an sp^3 content of up to 77%, plasmon energy of 27 eV, refractive index of 2.45, hydrogen content of about 30%, optical gap of up to 2.1 eV and RMS surface roughness of 0.04 nm.

Keywords: Electron cyclotron wave resonance; Tetrahedral amorphous carbon; High rate deposition

1. Introduction

The magnetic storage disk consists of an AlMg substrate, a NiP base layer, a Cr texturing layer, and a layer of ferromagnetic polycrystalline Co alloy which acts as the storage medium. The disk rotates rapidly and a read-write head 'flies' just above the disk on a hydrodynamic air bearing. It is found necessary to coat the disk and the head surface with a protective layer, to prevent wear and mechanical damage during head crashes. Diamond-like carbon (DLC) is nowadays the only material for this application, as it is able to make a smooth, very continuous film of low thickness.

The storage density of these disks is increasing rapidly, presently by about 50% per year [1], a similar rate to the speed increase of microprocessors. The density increase is possible by using ever smaller areas to hold each bit of data, and this requires lower head flying heights, and so thinner DLC layers. The next generation of disks requires DLC layers of order 10 nm thickness with a roughness of under 1 nm [2].

Presently, the DLC overcoats are hydrogenated amorphous carbon (a-C:H) deposited by reactive sputtering of graphite in an Ar, hydrogen atmosphere. Sputtering is used because it is used for the metal layers. However, there is doubt whether the quality of a-C:H formed by sputtering is suitable for future generations of magnetic disk. Other technologies are being considered.

Suitable technologies for carbon coating must be able to make continuous films of 5 nm thickness, under 1 nm roughness, at deposition rates of 10–20 nm in 8 s (that is, over 1.2 nm/s), with good uniformity over a certain area.

One such technology is the filtered cathodic vacuum arc (FCVA)[3,4]. This method creates an intense plasma beam of carbon ions which is then passed through an axial magnetic filter to remove particulates. This method is capable of forming highly smooth films of 0.05 nm RMS roughness and of very high hardness, 80 GPa at a high deposition rate of up to 3 nm/s [4]. The extreme properties of the tetrahedral amorphous carbon (ta-C) produced arise from the deposition from an almost fully ionised plasma beam.

Plasma enhanced chemical vapour deposition (PECVD) is another method frequently used to make a-C:H. However, PECVD must be carried out at a lower than usual pressure in order to give highly ionised plasma beams suitable for the best a-C:H. The plasma beam source (PBS) is one such source [5,6]. This is a RF excited, capacitively coupled source in which magnetic confinement is used to allow the plasma to operate at a low pressure of 10^{-4} mbar. The ta-C:H produced has good properties, such as hydrogen content below 30%, and up to 70% sp^3 bonding. However, this source is unsuitable for industrial usage because it only has a deposition rate is about 0.3 nm/s, and it has limited large area capabilities.

2. ECWR source

A new type of low pressure PECVD source has recently

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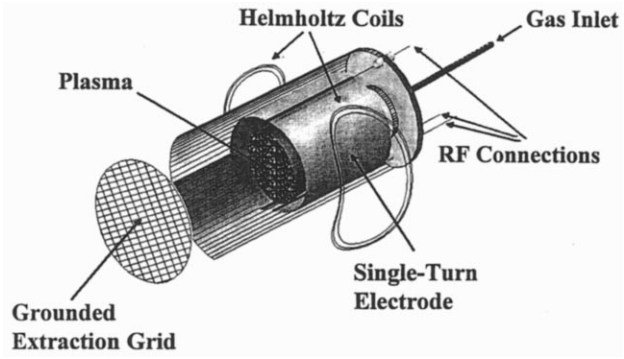

Fig. 1. Schematic diagram of the ECWR source.

been developed to overcome most of the limitations of the PBS [7]. This is based on the electron cyclotron wave resonance (ECWR) principle. A schematic of the ECWR is shown in Fig. 1. This source is a 13.6 MHz, single-turn inductively coupled source with a transverse magnetic field. The transverse magnetic field splits the electromagnetic wave into two circularly polarised waves. The right-hand polarised wave is no longer reflected by the plasma, but is strongly coupled to the bulk plasma, so allowing efficient power transfer from the RF to the plasma and enabling the formation of a high plasma density two orders of magnitude higher than in a capacitive source. The refractive index of the plasma is also increased so that a half-wavelength of the wave can now equal the chamber dimensions, and creates a resonant condition. The ECWR design is similar to the helicon, but there the magnetic field lies along the chamber axis and a different antenna must be used [8].

The plasma density and thus the ion current density from the ECWR reactor varies approximately linearly with the RF input power. The ECWR source also possesses a grounded extraction grid with an additional rear electrode, which allows the application of a capacitively coupled 13.6 MHz RF self bias voltage to vary the ion energy of the plasma beam. This allows the ion energy to be varied independently of the ion current/deposition rate [7]. A single RF power supply supplies the inductive electrode and the capacitive electrode via a matching network.

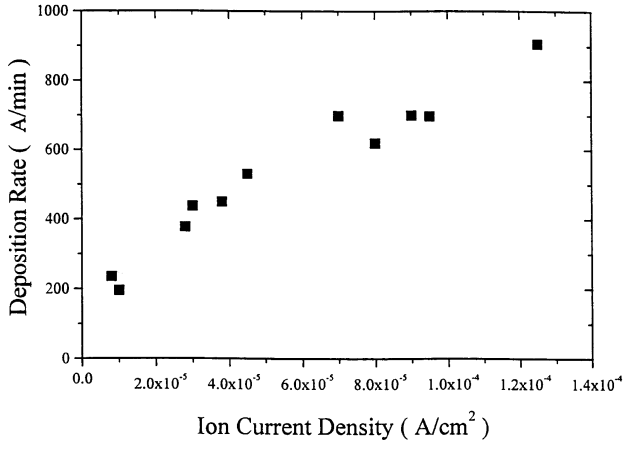

Fig. 2. Variation of growth rate with ion current density, as RF power is increased.

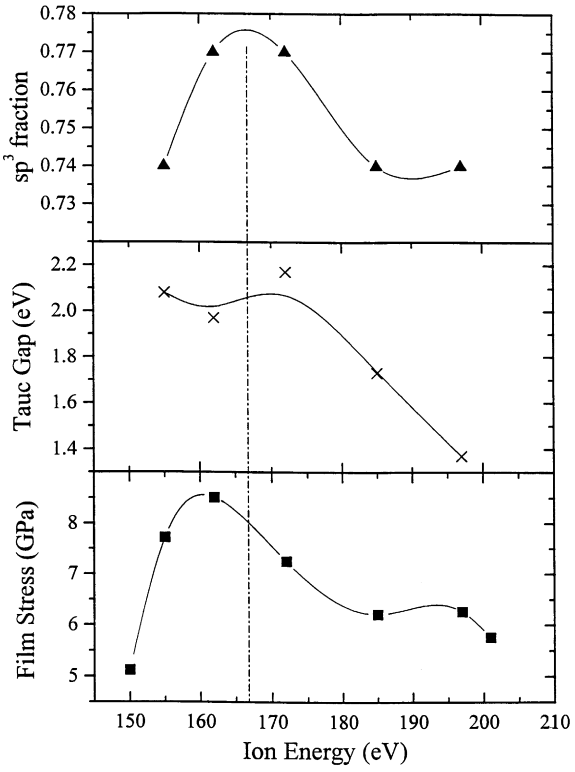

Fig. 3. Variation of sp^3 fraction, optical gap and compressive stress in the ta-C:H films as a function of incident ion energy.

3. Ta-C:H films

The ECWR reactor was tested in a UHV chamber pumped by a 1300 l/s diffusion pump. A nitrogen plasma was measured using a double Langmuir probe to have a plasma density of between 10^{10} and 10^{11} cm^{-3}. The ion current was measured by a Faraday cup. For an acetylene plasma at 2×10^{-3} mbar, an ion current density of up to 0.14 mA/cm^2 can be obtained at a RF power of 500 W, corresponding to a deposition rate of 1.5 nm/s (Fig. 2). This rate is sufficient for magnetic disk applications. The area uniformity is 5% over 4 inches [7].

The ta-C:H films were deposited onto silicon or quartz substrates held at room temperature. The sp^3 content was measured by electron energy loss spectroscopy (EELS). As in other ta-C and ta-C:H systems, the sp^3 fraction varies with ion energy (Fig. 3), and reaches a maximum of 77% at an ion energy of 166 eV for acetylene. EELS was also used to derive the valence plasmon energy, which can be used as a measure of the density. The plasmon energy reached 27 eV. A mass density of about 2.38 g/cm^3 was derived from X-ray reflectivity.

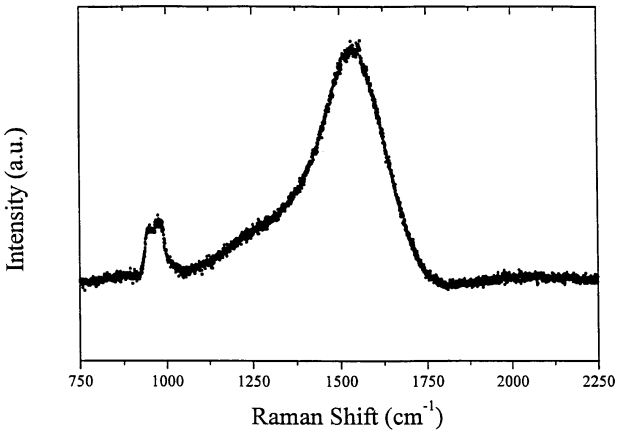

Fig. 4. Raman spectrum.

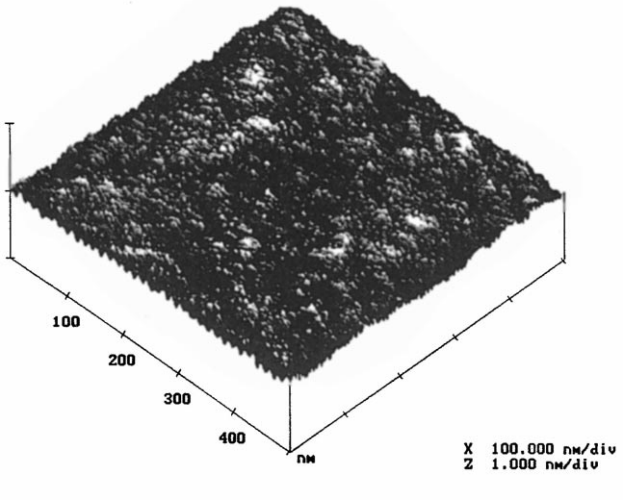

Fig. 5. AFM image of the ta-C:H surface. RMS roughness of 0.03 nm.

The optical properties of the films were measured by a UV-vis spectrometer. The Tauc gap was found to be 2.1 eV and the E_{04} gap 2.6 eV. The refractive index is a good measure of the degree of diamond-like bonding in DLC films, with higher values indicating higher diamond-like quality. The refractive index was found to be 2.45.

The hydrogen content of the films was measured by ERDA as just over 30%. The infrared spectrum shows that the majority of the hydrogen is bonded as sp^3 C–H and C–H_2 groups. The IR spectrum also shows C–C vibrations at 1536 cm^{-1} and 1680 cm^{-1}, due to graphitic and olefinic groups respectively. This is the first time the olefinic groups have been so apparent in the C–C part of the IR spectrum of a DLC.

The Raman spectrum is also used as a diagnostic of bonding in DLC films (Fig. 4). The spectrum shows a strong G peak at 1550 cm^{-1}, and only a weak 'D' shoulder at 1345 cm^{-1} (the peak at 975 cm^{-1} is due to the Si substrate). This Raman spectrum is intermediate between the almost symmetric G peak spectrum of ta-C [9], and that of regular a-C:H with a slightly stronger D shoulder [10]. Further work is being carried out to relate the spectrum to the sp^3 content.

Fig. 5 shows an atomic force microscope (AFM) image of the surface topology. The roughness can be estimated as an RMS roughness of under 0.03 nm. This is sufficient for disk coating applications of the future.

References

[1] E. Grochowski, D.A. Thompson, IEEE Trans. Mag. 30 (1994) 3797.
[2] M.F. Doerner, R.L. White, MRS Bull. Sept. (1996) 28.
[3] P.J. Fallon, V.S. Veerasamy, C.A. Davis, J. Robertson, G.A.J. Amaratunga, W.I. Milne, J. Koskinen, Phys. Rev. B 48 (1993) 4777.
[4] S. Xu, D. Flynn, B.K. Tay, S. Prawer, K.W. Nugent, S R.P. Silva, Y. Lifshitz, W.I. Milne, Phil. Mag. B 76 (1997) 351.
[5] M. Weiler, S. Sattel, T. Giessen, K. Jung, H. Ehrhardt, J. Robertson, Phys. Rev. B 53 (1996) 1594.
[6] S. Sattel, J. Robertson, H. Ehrhardt, J. Appl. Phys. 82 (1997) 4566.
[7] M. Weiler, K. Lang, E. Li, J. Robertson, Appl. Phys. Lett. 72 (1998) 1314.
[8] M.A. Lieberman, A.J. Litchenberg, Principles of Plasma Discharges and Materials Processing, Wiley, New York, 1994.
[9] S. Prawer, K.W. Nugent, Y. Lifshitz, G.D. Lempert, E. Grossman, J. Kulik, I. Avigal, R. Kalish, Diamond Rel. Mater. 5 (1996) 433.
[10] M.A. Tamor, W.C. Vassell, J. Appl. Phys. 76 (1994) 3823.