DEPOSITION OF TiN THIN FILMS WITH STRONGLY IONIZED PLASMAS IN HIGH DUTY AC TOKAMAK DISCHARGE

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Abstract

A good TiN thin film formation by reactive sputtering is obtained in high duty AC tokamak with strongly ionized plasmas with a high charged particle density beyond 10^{18} m^{-3} , in an extremely low gas pressure of the order of 10^{-5} Torr. The deposited thin films were analyzed by various surface diagnostics (SEM, EDAX, XPS, RBS).

1. Introduction

Many kinds of plasma sources have been developed for material processing. Tokamak discharges with reactive gases as a working gas have been proposed as novel plasma sources for material processing since tokamak discharges have outstanding characteristics of high plasma density and extremely low neutral gas pressure($\leq 10^{-4}$ Torr), a very long mean free-path of radicals as well as charged particles, a modest consumption of an expensive working gas by efficient dissociation and ionization, low ionic energy coming from a low toroidal turn voltage compared with high voltage in RF or DC discharges[1,2]. But the conventional tokamak discharge is always in low duty operation. Recently a fully continuous AC tokamak operation with a plasma current of 600A and a frequency of 60-100Hz has been achieved for one minute in the small tokamak device CSTN-AC[3].

As one of the application of such an AC toroidal plasma source, a thin film formation of titanium nitride (TiN) by reactive sputtering in CSTN-AC tokamak will be reported in this paper. This film is of commercial interest because of its industrial applications including hard wear-resistant coating on cutting tools[4,5], high infa-red reflectance, [6] diffusion barriers of integrated circuits[7].

2. Experimental setup

CSTN-AC tokamak has the major radius R=0.4m, the minor radius r=0.1m. The typical discharge parameters are the plasma current Ip $\leq$1kA, the loop voltage Vp $\leq$10V, the electron density at the center of the chamber $n_e \leq 5\times10^{18} m^{-3}$ for nitrogen plasma, the central electron temperature Te $\leq$15eV, the toroidal magnetic field Bt ~0.1T. The base pressure is the order of

10^{-7} Torr. The duty of AC discharges can be controlled arbitrarily from less than 1% to 100%. But considering heat load to the chamber wall, the maximum duty factor is limited at 30%, which means we have 30 discharges (1 discharge = 0.01s) every second.

A titanium target plate with water cooling and a temperature controlled holder for silicon substrate are set in the vacuum chamber as shown in Fig. 1. The plasma region is limited by the limiter. The Ti target and wall are cleaned by argon sputtering with argon discharge for one hour every time before starting any film depositions. This may reduce the effect of impurities (O_2, H_2, H_2O, etc) on film formation. A pure nitrogen gas is used as a working gas in the present TiN film formation. The Ti target plate for sputtering by nitrogen ion impact was negatively biased up to -160V. The plasma parameters are measured by the triple probe. The deposited thin films were analyzed by various surface diagnostics (SEM, EDAX, XPS, RBS).

3. Experimental results

3.1 Nitrogen plasma properties generated in AC-tokamak

The TiN thin films were formed by about 1~2 hours nitrogen discharges with 20% or 30% duty factor. The gas pressure is controlled less than 10^{-4} torr. The plasma density can be controlled by changing the input power, mainly the toroidal plasma current. Figure 2 shows some typical waveforms of the plasma current Ip, the loop voltage Vp, the current flowing into the biased target plate It, and the electron density n_e and the electron temperature Te for nitrogen

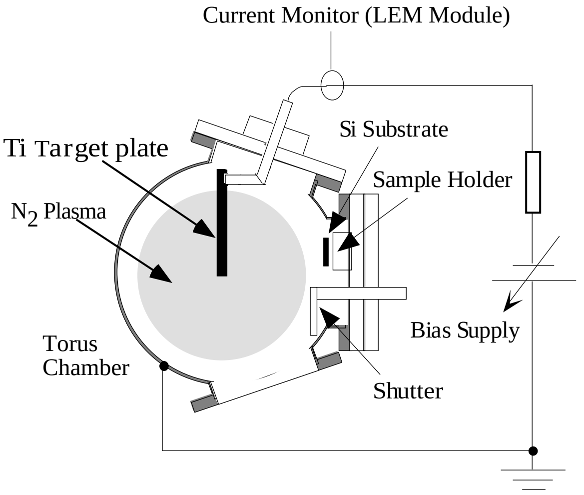

Fig. 1. Poloidal cross section of experimental setup for thin film formation.

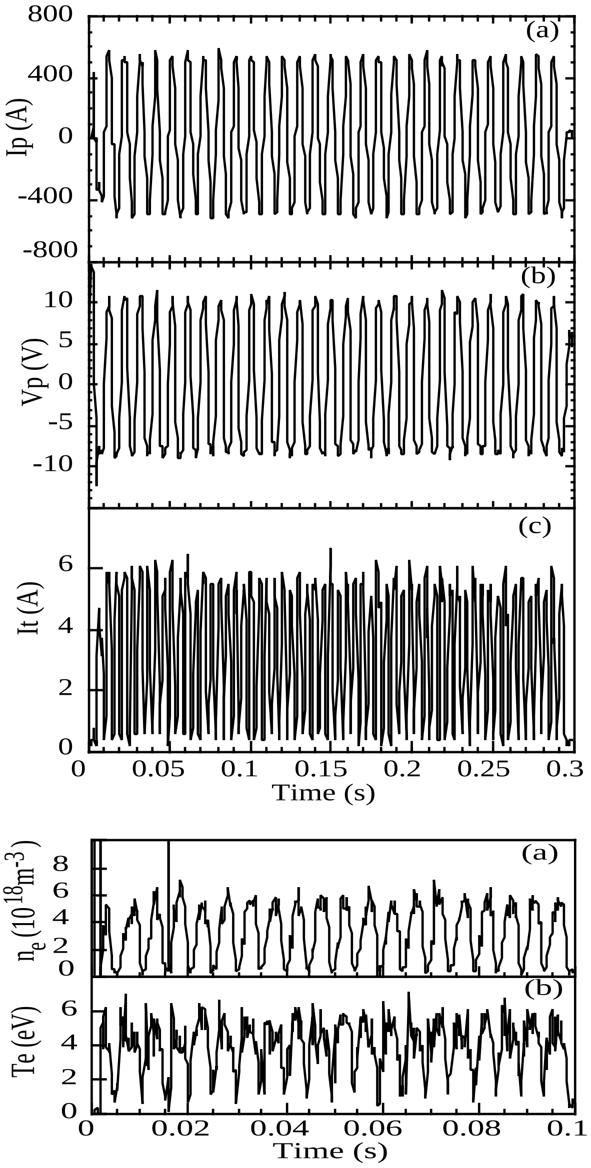

Fig. 2. Time evolution of the discharge and plasma parameters.

plasma in the case of AC discharge with 30% duty. The time evolution of some spectral line intensities of nitrogen molecules, molecular ions and atomic ions are shown in Fig. 3. As seen, a high density and a low electron temperature nitrogen plasma is obtained at high duty discharge in CSTN-AC tokamak. The substrate temperature is controlled at about 320°C~350°C during film deposition.

3.2 TiN thin film formation

The deposited film has an uniform golden colour. The relative ratio of nitrogen and titanium (N/Ti) is given about 1.10 in the film by XPS and RBS. Figure 4 shows the spectra of the deposited films obtained by RBS. The conditions of film deposition in Fig. 4 are listed in Table I. It is found that the film thickness increases in the case of high plasma current as shown in Fig. 4(b) compared with the case in Fig. 4(a). It may be explained by a high Ti flux sputtered by the high ion density, since the current flowing into the target in the case (b) is 1.5 times as large as that in the case (a) at the same biasing voltage. The film thickness of about 100nm is obtained in the case of Fig. 4(a).

A very smooth surface structure and no columnar structure are observed by Scanning Electron Microscopy (SEM). This may mean that the formed TiN crystal size is small, and the columnar morphology is destroyed.

Figure 5 shows the EDAX (Energy Dispersive X-ray Analysis) spectra of the film, showing no discernible impurity problem. But it should be noted that some samples analyzed by XPS and RBS in Japanese company show that the relative ratio of Oxygen and titanium O/Ti = 0.13 in the deep inside. Oxygen impurity could be reduced by further improving base pressure and wall conditioning.

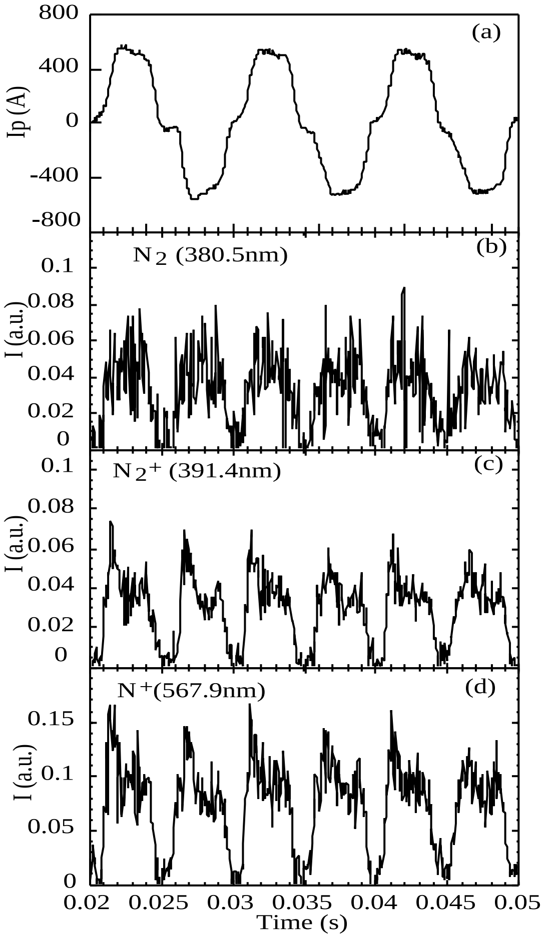

Fig. 3. Time traces of some spectral line intensities for nitrogen molecules, molecular ions and atomic ions as well as plasma current.

Table I The conditions of films deposition

	Case (a)	Case(b)
Duty [%] (1Hz)	30	20
Deposition time [min]	120	120
P(N_2) [Torr]	$\sim 8.5\times10^{-5}$	$\sim 5.0\times10^{-5}$
Ip [A]	530	800
Vp [V]	10	10
Biasing voltage [V]	-160	-160
It [A]	6	9
Substrate temperature [^{0}C]	320	320
Base pressure [Torr]	5.8×10^{-7}	7.8×10^{-7}

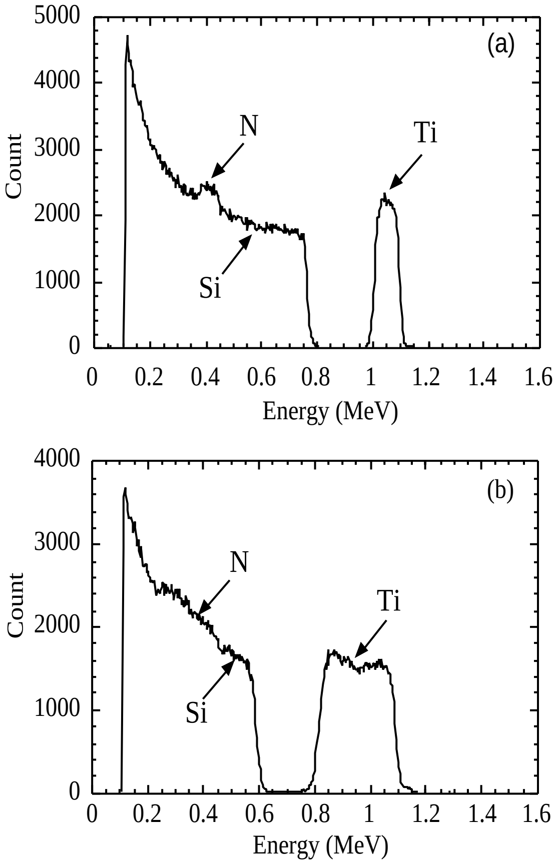

Fig. 4. RBS spectra of the TiN thin films Case (a) and Case (b).

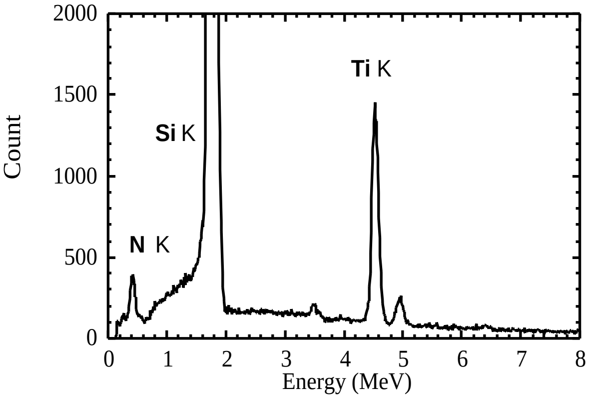

Fig. 5. EDAX spectra of the TiN thin film.

4. Discussions

As the first application of the high duty toroidal plasma source, CSTN-AC tokamak , to material processing, TiN thin film are successfully formed in the device.

A high ion current density up to about 0.2A/cm^2 have been obtained at the target plate with high nitrogen plasma density at biasing voltage of -160V. It is noted that an arcing may occur locally on the target at a higher biasing voltage. The higher duty of discharge is limited by heat load to the chamber wall[3]. It may be solved by considering a water cooling of vacuum chamber.

Acknowledgments

The authors would like to thank Dr. J. Yuzuhara (Nagoya University) for valuable discussions and technical help for RBS analysis.

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