

# High-rate low-temperature dc pulsed magnetron sputtering of photocatalytic TiO<sub>2</sub> films: the effect of repetition frequency

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**Abstract** The article reports on low-temperature high-rate sputtering of hydrophilic transparent TiO<sub>2</sub> thin films using dc dual magnetron (DM) sputtering in Ar + O<sub>2</sub> mixture on unheated glass substrates. The DM was operated in a bipolar asymmetric mode and was equipped with Ti(99.5) targets of 50 mm in diameter. The substrate surface temperature  $T_{\text{surf}}$  measured by a thermosstrip was less than 180 °C for all experiments. The effect of the repetition frequency  $f_r$  was investigated in detail. It was found that the increase of  $f_r$  from 100 to 350 kHz leads to (a) an improvement of the efficiency of the deposition process that results in a significant increase of the deposition rate  $a_D$  of sputtered TiO<sub>2</sub> films and (b) a decrease of peak pulse voltage and sustaining of the magnetron discharge at higher target power densities. It was demonstrated that several hundreds nm thick hydrophilic TiO<sub>2</sub> films can be sputtered on unheated glass substrates at  $a_D = 80$  nm/min,  $T_{\text{surf}} < 180$  °C when high value of  $f_r = 350$  kHz was used. Properties of a thin hydrophilic TiO<sub>2</sub> film deposited on a polycarbonate substrate are given.

**Keywords** TiO<sub>2</sub> film · Hydrophilicity · Deposition rate · Unheated substrate · Dual magnetron sputtering · Polycarbonate

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## Introduction

Titanium dioxide (TiO<sub>2</sub>) is well known photocatalyst with good chemical stability, high refractive index, nontoxicity and good mechanical hardness. In recent years, photoinduced hydrophilicity characterized by the decrease of the water droplet contact angle (WDCA) to almost 0° on the TiO<sub>2</sub> films surface has been also reported. For these unique properties, TiO<sub>2</sub> can be used for the preparation of self-cleaning, anti-fogging and antibacterial self-sterilization coatings [1–3]. However, there are several problems which prevent a higher utilization of the TiO<sub>2</sub> photocatalyst. A photoexcitation of an electron-hole pair by photons with wavelengths less than 385 nm (UV light region) is required due to an optical bandgap energy  $E_g = 3.2$  eV for the TiO<sub>2</sub> anatase phase [4]. The photoexcited electrons and holes play a crucial role in the photocatalytic and hydrophilic behaviour of the TiO<sub>2</sub> films. Therefore, the first problem is connected with the activation of the TiO<sub>2</sub> films because the UV light covers only a small fraction of the total sun radiation.

This article is devoted to the low-temperature (low-T) sputtering of the TiO<sub>2</sub> films with deposition rates sufficient for industrial production. Such a process is urgently needed for the preparation of films on heat sensitive substrates, such as polymer foils, polycarbonate (PC), etc., at low substrate surface temperatures  $T_{\text{surf}}$ , e.g.  $T_{\text{surf}} < 130$  °C in the case of the polycarbonate [5]. Recently, it has been shown that  $T_{\text{surf}}$  can be much higher than that measured by a thermocouple incorporated in a substrate holder [6]. Among many preparation methods [7–12], the magnetron sputtering is a very promising technology for a low-temperature deposition of the high-quality crystalline hydrophilic

TiO<sub>2</sub> films. Several authors have reported on high-rate sputtering of the transparent amorphous TiO<sub>2</sub> films. The preparation of the crystalline hydrophilic TiO<sub>2</sub> films at a low-T without post-deposition thermal annealing, which can not be used, for instance, for the films sputtered on the PC substrate, remains an open problem [9, 11–19]. Therefore, this article is devoted to the optimization of the dual magnetron sputtering process for the low-T deposition of the TiO<sub>2</sub> films. The effect of the repetition frequency  $f_r$  on the pulse waveforms, deposition rate  $a_D$ , substrate surface temperature  $T_{\text{surf}}$ , film structure and hydrophilic properties is discussed in detail. Trends of the next development are also briefly outlined.

## Experimental

The transparent TiO<sub>2</sub> films were prepared by reactive magnetron sputtering in a mixture of Ar + O<sub>2</sub> by dc pulsed dual magnetron equipped with Ti(99.5) targets of 50 mm in diameter. The magnetron was supplied by a dc pulsed Advanced Energy Pinnacle Plus + 5 kW power supply unit (PSU) operating in a bipolar asymmetric mode and duty cycle  $\tau/T = 0.5$ ; here  $\tau$  and  $T$  are the length of pulse and the period of pulses, respectively. The PSU in bipolar asymmetric mode can be operated with a repetition frequency  $f_r$  ranging from 100 to 350 kHz. Further details on the dual magnetron system are given elsewhere [20]. The films were deposited on unheated microscope glass slides ( $26 \times 26 \times 1 \text{ mm}^3$ ) and unheated polycarbonate (PC) substrates ( $26 \times 26 \times 3 \text{ mm}^3$ ). The TiO<sub>2</sub> films with a constant thickness  $h \approx 1,000 \text{ nm}$  were prepared in order to avoid a strong influence of the film thickness  $h$  on their properties [6, 21].

The thickness of the films was measured by a stylus profilometer DEKTAK 8 with the resolution of 1 nm. The structure of the films was determined by X-ray diffraction (XRD) analysis using a PANalytical X'Pert PRO diffractometer working in Bragg-Brentano geometry using a CuK $\alpha$  (40 kV, 40 mA) radiation. The water droplet contact angle (WDCA)  $\alpha_{\text{ir}}$  on the surface of the TiO<sub>2</sub> films after their irradiation by the UV light (Philips TL-DK 30 W/05,  $W_{\text{ir}} = 0.9 \text{ mW cm}^{-2}$ ,  $\lambda = 365 \text{ nm}$ ) was measured by a Surface Energy Evaluation System (Masaryk University in Brno, Czech Republic). The surface roughness  $R_a$  was measured by atomic force microscopy (AFM) in non-contact mode using an AFM-Metris-2000. The measurements were performed in ambient atmosphere at room temperature. The substrate surface temperature

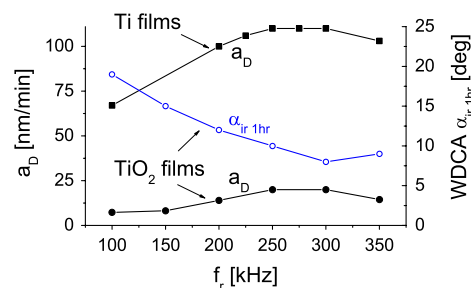
$T_{\text{surf}}$  was measured by the thermostrips (Kager GmbH, Germany). More details are given in Ref. [6].

## Results and discussion

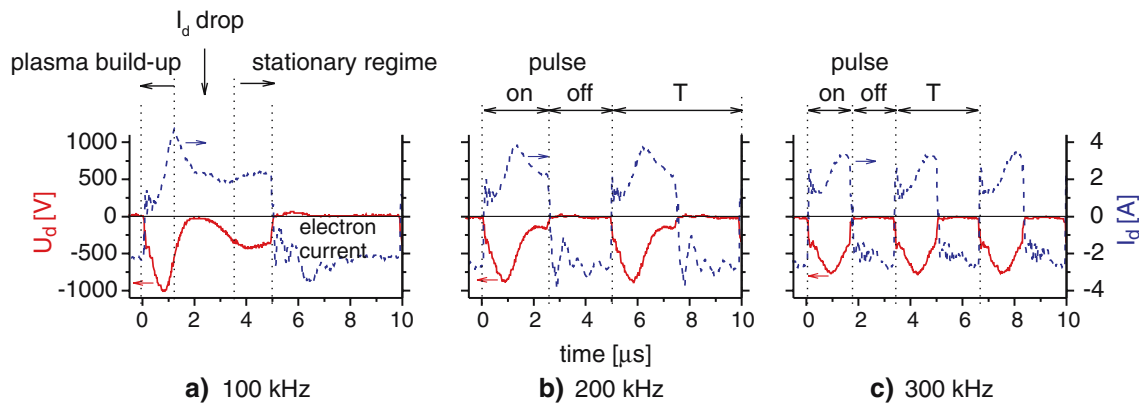
Recent results have shown that the low-T sputtering of the crystalline hydrophilic TiO<sub>2</sub> films with the anatase structure can be realized in the oxide mode [6, 21]. A systematic investigation of the correlations between the deposition process parameters and the properties of the TiO<sub>2</sub> films showed that an increase of repetition frequency  $f_r$  from 100 to 350 kHz at constant values of  $p_T = 0.9 \text{ Pa}$ ,  $I_{\text{da}1,2} = 3 \text{ A}$  and  $d_{s-t} = 100 \text{ mm}$  results in a significant increase of the film deposition rate  $a_D$  in both the metallic ( $p_{\text{O}_2} = 0 \text{ Pa}$ ) and oxide mode (0.15 Pa) of sputtering, see Fig. 1. An improvement of the photoinduced hydrophilicity of the TiO<sub>2</sub> films with increased  $f_r$  was observed as well. However, only a slight increase of maximum substrate surface temperature  $T_{\text{surf}}$  from 160 to 180 °C was measured when  $f_r$  increased from 100 to 350 kHz. These effects are further discussed in detail.

### Time evolution of pulse waveforms

The time evolution of the pulse waveforms of current  $I_d$  and voltage  $U_d$  in the dual magnetron discharge generated in the oxide mode of sputtering ( $p_{\text{O}_2} = 0.15 \text{ Pa}$ ) at different values of the repetition frequency  $f_r$ , average discharge current  $I_{\text{da}1,2} = 3 \text{ A}$  and  $p_T = 0.9 \text{ Pa}$  are displayed in Fig. 2. Here, the waveforms in one channel of the dual magnetron are given. The waveforms in the second channel are shifted by a half of the period  $T$ . This experiment shows that the time evolution of voltage at  $f_r = 100 \text{ kHz}$  can be



**Fig. 1** The effect of the repetition frequency  $f_r$  on (1) the deposition rate  $a_D$  of (a) the Ti films sputtered in the metallic mode ( $p_{\text{O}_2} = 0 \text{ Pa}$ ) and (a) the TiO<sub>2</sub> films sputtered in the oxide mode ( $p_{\text{O}_2} = 0.15 \text{ Pa}$ ) at  $I_{\text{da}1,2} = 3 \text{ A}$ ,  $p_T = 0.9 \text{ Pa}$ , and  $d_{s-t} = 100 \text{ mm}$  and (2) the water droplet contact angle  $\alpha_{\text{ir}}$  on the surface of the TiO<sub>2</sub> films after UV irradiation ( $0.9 \text{ mW cm}^{-2}$ ) for 1 h



**Fig. 2** The time evolution of discharge voltage  $U_d$  and current  $I_d$  in the dc pulsed discharge generated by the dual magnetron equipped with Ti targets at  $I_{da1,2} = 3$  A,  $p_{O_2} = 0.15$  Pa (oxide

mode),  $p_T = 0.9$  Pa and three values of  $f_r = 100, 200$  and  $300$  kHz;  $I_{da1,2}$  is the discharge current averaged over the pulse length  $\tau$

divided into three regimes: (1) a strong overshooting (up to  $-1,100$  V) at the pulse beginning ( $t < 1$   $\mu$ s) corresponding to the build-up of the discharge and accompanied by a strong sputtering with a maximum at  $t = 1$   $\mu$ s, (2) a subsequent voltage drop below  $-100$  V ( $1 \leq t \leq 2$   $\mu$ s) when the discharge current approaches to a stationary value  $I_d \approx 3$  A and (3) a very low-voltage (less than  $-100$  V) regime with a very weak sputtering in the time interval from  $\sim 2$  to  $\sim 3$   $\mu$ s followed by a stationary regime at  $U_d \approx -400$  V and the interval of sputtering from  $\sim 3$   $\mu$ s to the end of the pulse. The shape of the voltage pulse waveform strongly influences the utilization of the sputtering within the pulse-on time. No sputtering takes place during the pulse-off time. This means that the period  $T = 10$   $\mu$ s is very ineffectively used for sputtering. Similar results have been reported by Welzl et al. for pulsed magnetron sputtered the MgO films [22].

However, it is clearly seen from Fig. 2 that the utilization of the period  $T = 10$   $\mu$ s ( $f_r = 100$  kHz) can be improved if  $f_r$  of the pulses is increased. Due to shortening of the pulses and cutting of the stationary regime only the first time interval with a strong sputtering is present and plasma build-up regime starts to dominate; see the time evolution of current at  $f_r = 200$  and  $300$  kHz. Moreover, operating in the plasma build-up regime leads to an intensification of the ion bombardment and the increase of energy delivered to the surface of the growing film by ions given by  $E_{bi}^* = E_i v_i \approx T_e^{3/2} n_e$  [23] where,  $E_i$  and  $v_i$  is the average energy of one bombarding ion and the flux of bombarding ions, respectively. Here the electron temperature  $T_e$  is significantly higher compared to the stationary regime, while the electron density  $n_e$  doesn't change remarkably, experimentally shown by Bradley et al. [24]. Shortening of the pulses also leads to a

higher preionization at the beginning of every pulse and thus the decrease of maximum overshooting voltage  $U_{max}$  and power loading  $W_{d max}$  that can prevent the thermal overloading of the target. This fact simultaneously results in the increase of the deposition rate in the oxide mode of sputtering from  $7.3$  to  $14.5$  nm/min for  $TiO_2$  films and  $67$  to  $103$  nm/min in the metallic mode for Ti films at  $f_r = 100$  and  $350$  kHz, respectively. Obtained results are summarized in Table 1.

The same time evolution of discharge current and voltage shown in Fig. 2 was measured for an arbitrary content of oxygen in the sputtering gas. It means that the results given above are valid for the transition, oxide and metallic mode of sputtering.

#### Effect of repetition frequency on XRD structure and hydrophilicity of $TiO_2$ films

The transparent  $TiO_2$  films with thickness  $h \approx 1,000$  nm were reactively sputtered in the oxide mode of sputtering ( $p_{O_2} = 0.15$  Pa) on the glass substrates at  $I_{da1,2} = 3$  A,  $d_{s-t} = 100$  mm,  $p_T = 0.9$  Pa and different values of the repetition frequency  $f_r$  ranging from  $100$  to  $350$  kHz. Under these deposition conditions, the substrate surface temperature  $T_{surf}$  increases with the increasing deposition time  $t_d$  and saturates at maximum value  $T_{surf max}$  after  $t_d > 20$  min [6]. In all the experiments  $T_{surf max} \leq 180$   $^{\circ}C$ .  $T_{surf max}$  increases from  $160$  to  $180$   $^{\circ}C$  when  $f_r$  is increased above  $200$  kHz; caused by the increase of the pulse target power density  $W_{da}$  and the substrate ion bombardment discussed above.

The structure of a  $TiO_2$  film also strongly influences the hydrophilicity of its surface. The evolution of the film structure with increasing  $f_r$  is displayed in Fig. 3. All the  $TiO_2$  films contain the anatase structure. This

**Table 1** The deposition rate  $a_D$  and average pulse magnetron voltage  $U_{da}$  in the metallic and  $a_D$ ,  $U_{da}$ , the target power densities  $W$ , maximum discharge voltage  $U_{max}$  and the substrate

surface temperature  $T_{surf}$  in the oxide mode for the Ti and  $TiO_2$  films sputtered at  $I_{da1,2} = 3$  A,  $d_{s-t} = 100$  mm,  $p_T = 0.9$  Pa and different repetition frequency  $f_r$  using the dual magnetron

$f_r$ [kHz]	metallic mode– $p_{O_2} = 0$ Pa		oxide mode– $p_{O_2} = 0.15$ Pa						
	$a_{D_{Ti}}$ [nm/min]	$U_{da}$ [V]	$a_{D_{TiO_2}}$ [nm/min]	$U_{da}$ [V]	$W_{da}$ [ $Wcm^{-2}$ ]	$W_d$ [ $Wcm^{-2}$ ]	$W_{d\ max}$ [ $Wcm^{-2}$ ]	$U_{max}$ [V]	$T_{surf}$ [°C]
100	67	–310	7.3	–387	58	29	180	–1100	160
200	100	–415	14	–462	70	35	140	–890	180
300	110	–440	20	–488	73	36.5	100	–770	180
350	103	–430	14.5	–452	68	34	100	–733	180

$W_{da}$ , average pulse power density;  $W_d$ , average period power density ( $W_d = W_{da} \cdot \tau / T$ );  $W_{d\ max}$ , maximum target power density;  $U_{max}$ , maximum discharge voltage

**Fig. 3** Development of the structure in the  $\sim 1,000$  nm thick transparent  $TiO_2$  films reactively sputtered on unheated glass substrates at  $I_{da1,2} = 3$  A,  $d_{s-t} = 100$  mm and  $T_{surf} \approx 160$ – $180^\circ C$ ,  $p_T = 0.9$  Pa and  $p_{O_2} = 0.15$  Pa with increasing  $f_r$

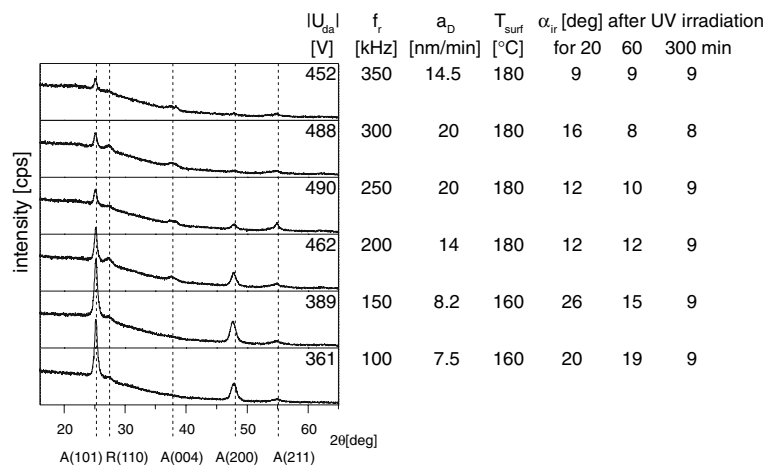


figure shows, that the increase of  $f_r$  leads to a partial suppression of the crystallinity characterized by the decrease of anatase (101) peak intensity. This phenomenon can be explained by a reduction of the energy delivered to the growing film by ions per deposited particle due to increasing deposition rate  $a_D$  ( $E_{bi} \approx E_{bi}^* / a_D$ ) [23]. However, the intensification of the ion bombardment at  $f_r > 200$  kHz discussed above ensures that the  $TiO_2$  films remain crystalline even at significantly higher deposition rates.

It was found that the deterioration of the anatase film crystallinity and the conversion of the anatase structured films to the close X-ray amorphous films improves the hydrophilicity. This finding is in a good agreement with previous reported results [21, 25]. The  $TiO_2$  films prepared at  $f_r = 350$  kHz exhibited best hydrophilicity; the WDCA  $\alpha$  on their surfaces decreases rapidly after 20 min of the UV irradiation to  $\alpha_{ir\ 20min} = 9^\circ$ . The surface roughness remains almost the same ( $R_a$  in the range from 9 to 10 nm) for all the  $TiO_2$  films prepared at different values of  $f_r$ . It means that an influence of the film surface morphology on the improvement of hydrophilicity can be excluded. This experiment shows that the increase in  $f_r$  opens a new possibility of the preparation of hydrophilic

transparent  $TiO_2$  films in the oxide mode of sputtering with significantly higher deposition rates compared to that of films produced at low  $f_r$  and even a better hydrophilicity.

The hydrophilicity improvement due to the increase of  $f_r$  is similar to the effect of the increased total working pressure  $p_T$  at  $f_r = 100$  kHz in the oxide mode of sputtering reported in Ref. [6], where the increase in  $p_T$  also resulted in the conversion of the  $TiO_2$  films with the anatase structure into the close to X-ray amorphous  $TiO_2$  films with suppressed anatase crystallinity and enhanced surface hydrophilicity.

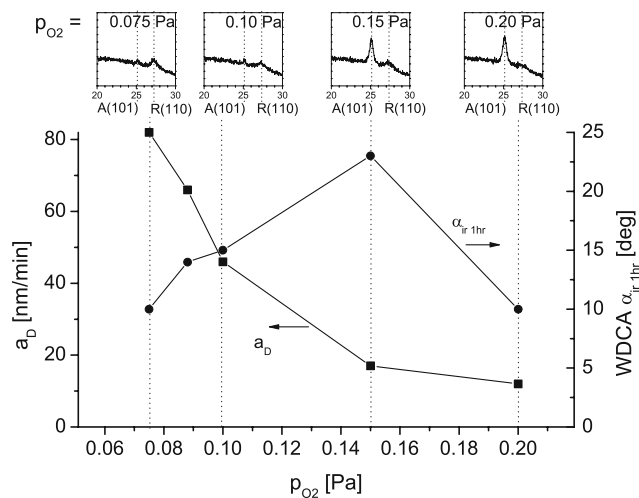
#### Effect of oxygen partial pressure $p_{O_2}$

A higher  $a_D$  of the  $TiO_2$  films can be achieved in the transition mode of sputtering (compared to the oxide mode). The operation in the transition mode was accompanied by the instabilities and the oscillations of the oxygen flow rates  $\phi_{O_2}$  at  $f_r > 200$  kHz and  $p_T = 0.9$  Pa when high values of  $I_{da1,2} \geq 3$  A are used. The deposition process was stable at  $f_r = 100$  kHz, i.e. no oscillations occur. The cause of this phenomenon is a greater amount of Ti atoms sputtered at  $f_r > 200$  kHz what requires a higher value of  $\phi_{O_2}$  to form  $TiO_{x \approx 2}$

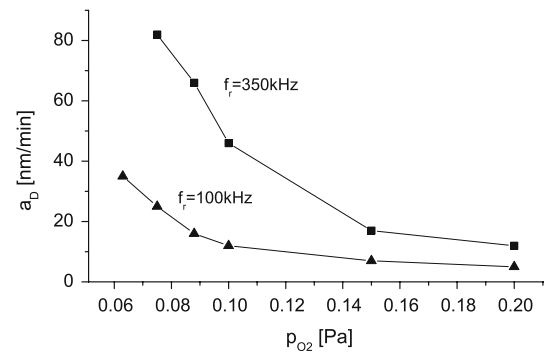
film together with desired oxygen partial pressure  $p_{O_2}$ . In this case the total flow rate of sputtering gas mixture  $\phi_T = \phi_{Ar} + \phi_{O_2}$  exceeds a critical value given by the pumping speed of the system, which results in a slower system response leading to instabilities in a closed control circuit [26, 27]. The closed control loop is discussed in detail in Ref. [20]. While the total working pressure  $p_T$  in the system is controlled by the pumping speed, instabilities can be suppressed if operating at decreased  $p_T$  and thus higher pumping speed of the vacuum system.

Based on the process stability study discussed above the experiments were carried out at  $f_r = 350$  kHz,  $I_{da1,2} = 3$  A and  $p_T = 0.75$  Pa. A series of the  $\sim 1,000$  nm thick  $TiO_2$  films at different  $p_{O_2}$  were prepared. All the films were sputtered at  $T_{surf} \leq 180$  °C. As expected,  $p_{O_2}$  strongly influences the film structure, its hydrophilicity and the deposition rate  $a_D$ , see Fig. 4. The increase of the oxygen partial pressure  $p_{O_2}$  leads to (i) a decrease of the deposition rate  $a_D$  of the transparent  $TiO_2$  films from 80 nm/min in the transition mode to 15 nm/min in the oxide mode, (ii) a change in the film structure from a mixture of the rutile + anatase in the transition mode of sputtering ( $p_{O_2} < 0.15$  Pa) to the anatase film in the oxide mode ( $p_{O_2} \geq 0.20$  Pa).

The anatase  $TiO_2$  film prepared at high value of  $p_{O_2} = 0.20$  Pa exhibits a very good hydrophilicity and low WDCA  $\alpha_{ir, 1h} < 10^\circ$  after the UV irradiation for one hour. The decrease of  $p_{O_2}$  leads to a deterioration of film hydrophilicity, except the  $TiO_2$  film sputtered with  $a_D = 80$  nm/min in the deep transition mode at



**Fig. 4** The deposition rate  $a_D$ , UV induced hydrophilicity characterized by WDCA  $\alpha_{ir, 1hr}$  after 1 h of UV irradiation ( $0.9$  mW  $cm^{-2}$ ) and the X-ray structure of 1,000 nm thick transparent  $TiO_2$  films prepared at  $I_{da1,2} = 3$  A,  $p_T = 0.75$  Pa,  $d_{s-t} = 100$  mm,  $f_r = 350$  kHz and  $T_{surf} \approx 180$  °C as a function of  $p_{O_2}$



**Fig. 5** The effect of the oxygen partial pressure  $p_{O_2}$  on the deposition rate  $a_D$  of the  $TiO_2$  films sputtered at  $I_{da1,2} = 3$  A,  $p_T = 0.75$  Pa,  $d_{s-t} = 100$  mm and different repetition frequency (a)  $f_r = 100$  kHz [6] and (b)  $f_r = 350$  kHz

$p_{O_2} = 0.075$  Pa, which also exhibited hydrophilic properties. This is in a good agreement with our previous reported results, where the same hydrophilicity was observed on the anatase films sputtered in the oxide mode and the anatase + rutile films sputtered at very low  $p_{O_2}$  in the transition mode. The deterioration of the film hydrophilicity in the transition mode is explained the decrease of the highly photoactive anatase phase content in the films in favor of the rutile phase. The high photoactivity of the films sputtered at very low  $p_{O_2}$  in the transition mode of sputtering is a result of their very high surface roughness that increases in the transition mode of sputtering with decreasing  $p_{O_2}$ ; for more details see Refs. [21, 28].

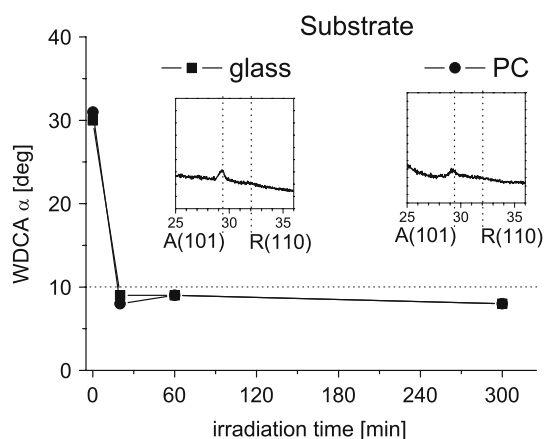
The effect of  $p_{O_2}$  on the deposition rate of the  $TiO_2$  films sputtered at above described deposition conditions and different repetition frequency  $f_r = 100$  kHz [6] and 350 kHz is shown in Fig. 5. As expected, the pulse waveforms evolution and operating in the plasma build-up regime with more effectively used sputtering pulse at  $f_r = 350$  kHz (discussed in section “Time evolution of pulse waveforms”) leads to significantly higher deposition rates even in the transition mode of sputtering.

#### $TiO_2$ deposition on thermal sensitive substrate

At present, there is an urgent need to deposit thin films on thermal sensitive substrates, such as the polycarbonate (PC). However, that is a very difficult task. In this section we report on a successful deposition of the  $TiO_2$  films on the PC at the substrate surface temperature  $T_{surf} < 130$  °C. This experiment is based on our recent investigations that clearly show that  $T_{surf}$  can be effectively driven by the pulse target power density [6, 23].

The well hydrophilic  $\sim 1,000$  nm thick transparent  $TiO_2$  films were sputtered with  $a_D = 5.2$  nm/min on the

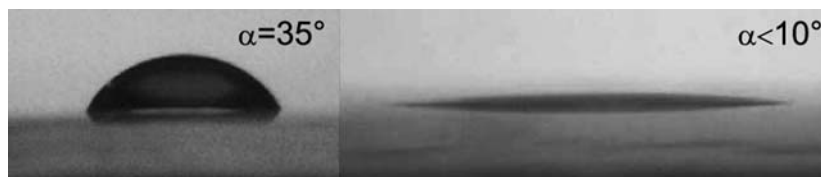




**Fig. 6** The X-ray structure of the 1,000 nm thick transparent TiO<sub>2</sub> films sputtered on glass and polycarbonate substrates at  $f_r = 350$  kHz,  $I_{da1,2} = 2$  A,  $p_T = 0.9$  Pa,  $p_{O_2} = 0.2$  Pa,  $d_{s-t} = 100$  mm,  $T_{surf} \approx 120$  °C and  $a_D = 5.2$  nm/min and their hydrophilicity as a function of time of UV irradiation

PC and glass substrates at  $I_{da1,2} = 2$  A,  $U_{da} = -400$  V,  $f_r = 350$  kHz,  $p_T = 0.9$  Pa,  $d_{s-t} = 100$  mm, oxide mode of sputtering at  $p_{O_2} = 0.15$  Pa and  $T_{surf} \approx 120$  °C. The XRD structure and hydrophilicity of these films is displayed in Fig. 6. The XRD patterns with broad low-intensity anatase (101) peaks confirm the nanocrystalline structure of the sputtered films and no difference in the photoinduced hydrophilicity characterized by the WDCA  $\alpha$  after the UV irradiation show that the substrate has no effect on the TiO<sub>2</sub> film properties. Both films exhibit an excellent photoinduced hydrophilicity with a very fast decrease of the WDCA with increasing the UV light irradiation time ( $\alpha_{irr20min} = 9^\circ$  already after  $t = 20$  min). Already very short UV irradiation converts the surface of the sputtered TiO<sub>2</sub> film into superhydrophilic one. The change in wettability of the surface of the TiO<sub>2</sub> film sputtered on the PC substrate after its UV irradiation for 20 min is shown in Fig. 7.

Obtained results clearly show that reactive pulsed dual magnetron sputtering is a one-step process suitable for the low-T preparation of the hydrophilic crystalline TiO<sub>2</sub> films on heat sensitive substrates.



**Fig. 7** Photos of the water droplet profile on the surface of the TiO<sub>2</sub> film sputtered on polycarbonate substrate at  $T_{surf} < 120$  °C (a) before and (b) after UV light irradiation for 20 min

However, the coating of very heat sensitive substrates such as PC ( $T_{max} = 130$  °C) has to be performed at decreased average pulse target power densities ( $\leq 40$  W/cm<sup>2</sup>) and low ( $\leq 5$  nm/min) deposition rates.

## Conclusions

Experiments described above clearly demonstrate that (i) dc pulsed reactive magnetron sputtering is a very perspective method for the low-T preparation of the crystalline hydrophilic TiO<sub>2</sub> films and (ii) the deposition process strongly depends on the pulse repetition frequency  $f_r$ . It was found that

1. The increase in  $f_r$  from 100 to 350 kHz and operating in plasma build-up regime results in (a) a strong increase of the deposition rate  $a_D$  of both Ti films sputtered at  $p_{O_2} = 0$  Pa (1.7 $\times$ ) and of TiO<sub>2</sub> films sputtered in the oxide mode at  $p_{O_2} = 0.15$  Pa (2 $\times$ ) while  $T_{surf}$  increases only slightly from 160 to 180 °C, (b) a decrease of peak discharge voltage which makes possible to sustain the magnetron discharge at high values of pulse target power densities achieving up to 240 W/cm<sup>2</sup> in our case.
2. The transparent hydrophilic TiO<sub>2</sub> film composed of a mixture of the anatase + rutile phase can be sputtered in the transition mode of sputtering at high deposition rate  $a_D = 80$  nm/min on glass substrate located at the substrate-to-target distance  $d_{s-t} = 100$  mm and  $T_{surf} \approx 180$  °C. The TiO<sub>2</sub> film with the excellent hydrophilic properties was successfully sputtered in the oxide mode at  $T_{surf} \approx 120$  °C,  $a_D = 5.2$  nm/min and  $f_r = 350$  kHz on a polycarbonate substrate without its thermal destruction.
3. The low-T deposition of the well hydrophilic TiO<sub>2</sub> films can be realized in a one-step process using the dc pulse reactive magnetron sputtering without a subsequent post-deposition thermal annealing.

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