§22. Quartz Crystal Microbalance Method for Real-time Dust Monitoring in LHD

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Development of real time dust monitoring methods for fusion devise is crucial to realize long-term safely operation because dust particles pose safety issues due to their chemical reactivity, tritium retention, and radioactive content. They may cause operational issues such as deterioration of plasma confinement. For these reasons, the maximum quantity of dust particles in the ITER vessel is limited below 6 kg of carbon or 11 kg of beryllium and 77 kg of tungsten.[1)] We aim to develop a dust monitoring method using quartz crystal microbalances (QCMs) equipped with a dust eliminating filter.[2-4)] The method offers simultaneous measurements of mass deposition rate of precursors responsible to film deposition and dust particles. Here we report results of a first operation of QCMs in a divertor simulator.

Dust particles were produced due to interactions between a graphite target and helicon H_2 plasmas in the divertor simulator. The QCMs were set on the reactor wall at 100 mm below the graphite target. The QCM sensors are cooled by water at 20 ^oC using a water cooling system. Gas of pure H_2 was supplied at a pressure of 5 mTorr. The gas was supplied at 13 sccm in flow rate at pumping port to reduce effects of gas flow on dust transport. H_2 plasmas were generated by applying 13.56 MHz pulsed RF voltage to a helicon antenna. The discharging period was 0.25 s, and the interval was 1.0 s to avoid overheating the quartz discharge tube. The QCM sensor has three channels. Channel 1 was used to measure deposition rate due to radicals and dust particles. Channel 2 was covered by a dust eliminating filter to measure the deposition rate due to radicals. For the filter, most of dust particles are deposited on the filter plate, while a part of deposition precursors such as CH_3 can pass through the filter because they are reflected on the filter plate. Channel 2 was covered by a SUS board to monitor effects of pressure and temperature on signals of QCMs.

A resonance frequency f of QCM is decreased by mass of deposits on the QCM. The deposition rate is deduced from the frequency shift (Δf) using the Saubrey equation given by

$$\Delta f = -2 f_0^2 A^{-1} (\mu_q \rho_q)^{-1/2} \Delta m, \qquad (1)$$

where Δf is frequency shift due to mass change on QCM, f_0 the fundamental resonance frequency of crystals, A area of QCM, μ_q the shear modulus of the quartz and ρ_q the density of crystal. Figure 1 shows time evolution of Δf of three QCMs. For ch. 1 and 2, Δf slightly increase just after turning on the discharge due to temperature and/or pressure change, then monotonically decrease. The rate of the frequency shift for ch.2 is much slower than that for ch.1. Δf for ch. 3 is nearly constant. Using eq. (1), deduced mass deposition rates for ch.1 ($DR_{\text{w/o filter}}$) and ch. 2 ($DR_{\text{w/ filter}}$) are 27.1 and 1.29 μg m^{-2} s^{-1}, respectively.

After discharges, carbon films were sampled from the filter surfaces and observed with the transmission electron microscope (TEM). Figure 2 shows TEM images of the films. Spherical grains below 20 nm in size are observed in the films sampled from the surface faced to discharges. They might be small particles deposited into films. On the other hands, a few grains are appeared in the films sampled from QCM under the filter. The volume of spherical dust in unit area for the surface of the filter and QCM under the filter are 2.09×10^{-9} and 1.22×10^{-10} m^3 m^{-2} , respectively. The eliminating ratio of dust particles in volume is 94.2 %. Thus, $DR_{\text{w/ filter}}$ is deposition rate predominantly due to radicals.

Thus the mass deposition rate of dust particles accumulated on vessel wall can be measured using the QCMs.

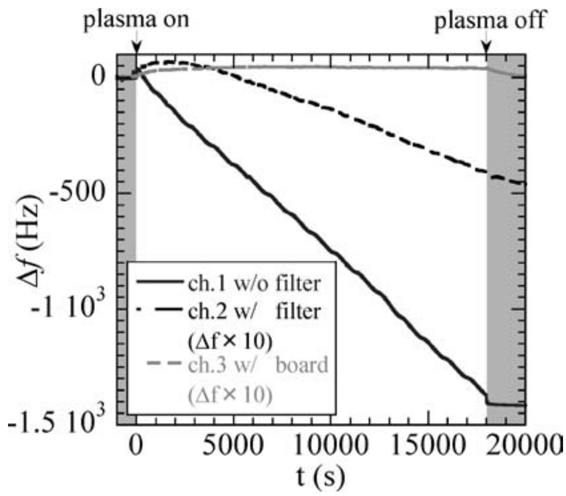

Fig. 1. Time evolution of resonance frequency shift of QCMs.

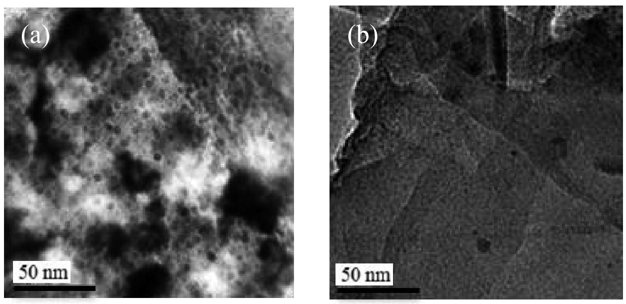

Fig. 2. TEM images of carbon films (a) without the dust eliminating filter, (b) with the filter.

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3) Kim, Y. et al.: Jpn. J. Appl. Phys. **52** (2013) 01AD01.
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