Transactions of the Materials Research Society of Japan 25 [2] 401-404 (2000)

High Performance Polymer Films for Air Cleaning Filter Fabricated by Mass-controlled Layer-by-layer Adsorption of Polyelectrolytes

Seimei S. Shiratori, Yuji Inami, Masashi Kikuchi,
Masayoshi Yamada and Takeshi Yamada

Department of Applied Physics & Physico-informatics,
Faculty of Science.& Engneering, Keio University,
3-14-1 Hiyoshi Kouhoku-ku Yokohama 223-8522, JAPAN
e-mail: shiratori@appi.keio.ac.jp FAX: ++81-45-563-0322

An extremely high performance smoke filter for air cleaner was established by forming the polymer thin films on the surface of fiberglass by layer-by-layer sequential adsorption of polyelectrolytes. The newly developed filter showed remarkably high performance because it can adsorb large amount of smoke without supplying electric power. Since the smoke is colloid aerosol and is positively or negatively charged, it showed remarkable adsorption characteristics to the film either polycation or polyanion layers owing to coulomb's force. By using automatic dipping machine for the layer-by-layer sequential adsorption film we have newly developed, polyelectrolytes films were formed by simply dipping the fiberglass into the solution. In addition, it is very easy to optimize the adsorption characteristics of the filter to smoke. It was also found that this filter can be cleaned just by rinsing with hot water at 90℃. Consequently, a remarkable high performance polymer filter for air cleaner can be produced by the mass-controlled layer-by-layer adsorption method of polyelectrolytes.

Key Words: filter, air cleaner, layer-by-layer, smoke, polyelectrolyte

1. Introduction

Non-smorking area is widely increasing in various locations such as airports, stations, trains and offices and smoking in only limited area is strongly enforced. In order to maintain comfortable circumstances for humans, it is very important to develop a good air cleaner. In the air cleaners, the performance of filter is essential to clean the air. At present, there are two types of commercial air cleaner. One is the paper type of filter with fine pore, which adsorb dust and small particles. The other is to charge the small particles by corona charging and gather the particle to the oppositely charged metal electrode. The former is the convenient disposable type filter, however, it is difficult to adsorb the small particles such as smoke. The latter is superior in adsorbing characteristics, however, it is unavoidable to supply electric power for charging the electrode or small particles. In addition, it is not easy for the maintenance or the cleaning of the electrode. Therefore, high performance filter with simple maintenance is required.

We have reported new fabrication method for the thin organic films: mass controlled [2-5] layer-by-layer sequential adsorption process[1,9]. We have reported that the thin organic films fabricated by this process have very high ability to adsorb smoke[5-8]. By utilizing this characteristic, we have reported the application as smoke sensor using a quartz crystal microbalance (QCM). Since the smoke is colloid aerosol and is positively or negatively charged, it showed remarkable adsorption characteristics to the film either polycation or polyanion layers because of coulomb's force.

By using these strong adhesion force, in this study, we applied these polymer thin films to the filter for air cleaner by forming the thin films on the surface of glass fiber cloth by layer-by-layer sequential adsorption of polyelectrolytes.

2. Experimental

The schematic image to show this new type of filter using the mass-controlled layer-by-layer

sequential adsorption process is shown in Fig.1

PAH (poly (allylaminehydrochloride)) was used as polycation and PAA (poly(acrylic acid)) was used as polyanion for the layer-by-layer self-assembly films and deposited on the surface of glass fiber cloth. After deposition, the cloth were dried at 90°C.

The experimental setup for the evaluation of the filter is shown in Fig.2. At first, vessel A (755ml) was filled with smoke from tobacco for 30sec. Then the entrance of the vessel A was covered with two sheets of filters. Thirdly, the entrance of the empty vessel B (55ml) was attached to the surface of the filters. The vessel B was detached 15 min later and the quantity of the smoke permeation through the filter was evaluated by smoke sensor using QCM[5-8].

The experimental setup for the evaluation of permeated smoke through the filter is shown in Fig.3..

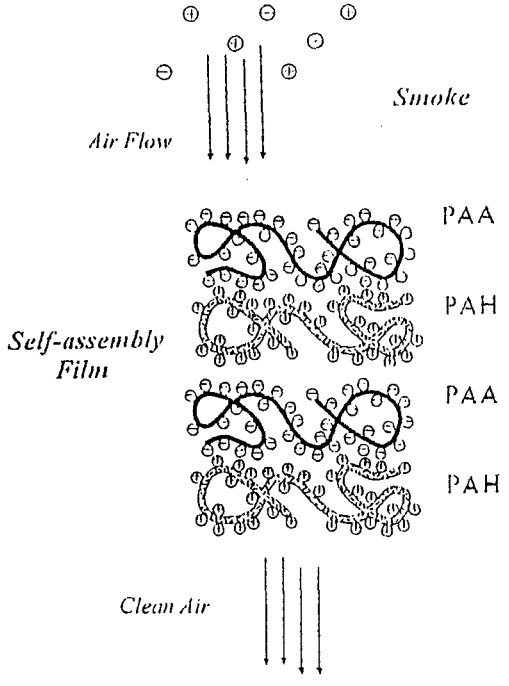

Fig.1 Schematic figure of smoke filter using layer-by-layer sequential adsorption films

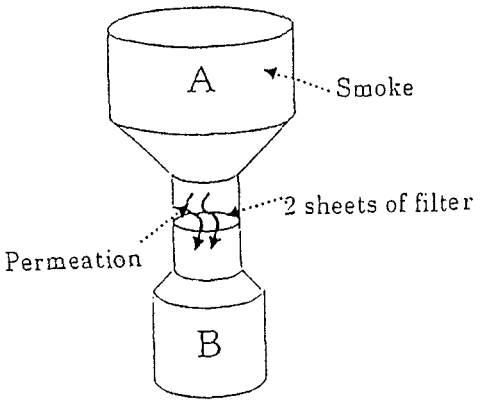

Fig.2 The experimental setup for the evaluation of the filter

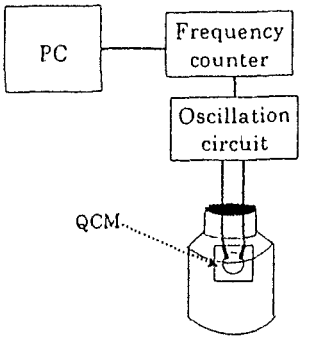

Fig.3 The experimental setup for the evaluation of permeated smoke through the filter

3. Results and Discussions

At first, in order to measure the mass increase of the polymer films after the adsorption of smoke, the polymer films were deposited on the electrode of QCM by using the mass controlled automatic dipping machine[2-4]. The mass ratios of PAH/PAA were 50/150, 67/133, 100/100, 133/67, 150/50, respectively. These numbers were shown by the unit of ng. Each QCM with thin polymer film was put into the 55ml vessel filled with smoke and the response characteristics of the frequency change was monitored. The results are shown in Fig.4. Both the adsorption and desorption characteristics are shown in this figure. As is shown in this figure, the best adsorption characteristics was observed when the ration of polycation/polyanion was approximately 2 (133/67).

The adsorption characteristic of smoke to PAH/PAA layer-by-layer self-assembly film as a

function of the number of the bilayers is shown in Fig.5. For this experiment, all the mass ratio of PAH/PAA was 2/1 and the adsorption characteristics of 30,60,90 and 150 bilayers of the films deposited on the QCM were compared. As is shown in this figure, the adsorption quantity of smoke increase as the increase of the number of bilayers. This result indicate that the smoke particles can permeate into the filter because the pore size of the membrane is large enough compared with the size of smoke particles (~0.01 μ m).

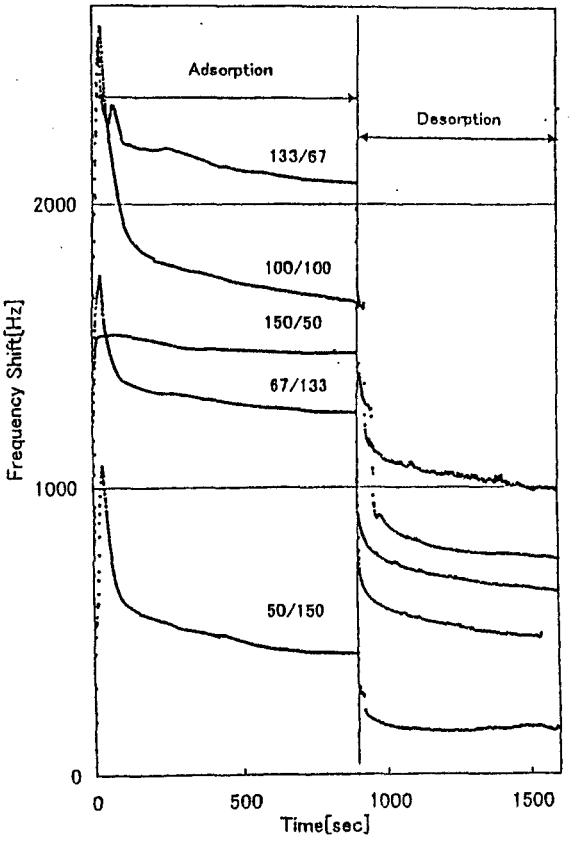

Fig.4 Smoke adsorption characteristics as the function of mass ratio of polycation and polyanion.

By using QCM, we have found that the adsorption characteristics were maintained at least 20 cycles. The mass decrease after 20 cycles shown in this figure indicate that removal of the membrane. The mass increase before the 20 cycles indicate that the quantity of the small particles remain inside of the films increase because of the strong adhesion between the particle and the membrane. We consider that the increase of the smoke particles inside of the film resulted in the decrease of the electrostatic binding force of the polycation and polyanion membrane. This may caused in the removal of the membrane after the 20 cycles.

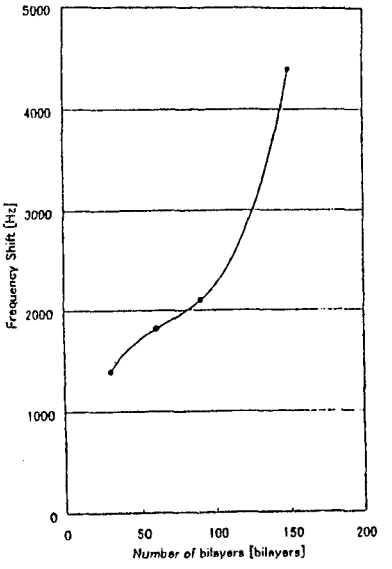

Fig.5 The adsorption characteristic of smoke to PAH/PAA layer-by-layer self-assembly film as a function of the number of the bilayers.

Next, the fiber glass cloths were used as the substrates and the mass controlled layer-by-layer self-assembly films were deposited on top of them. Adsorption characteristic of the film as the filter for air cleaner was evaluated by changing the number of bilayers and the strength of the polycation materials.

The permeation characteristics of smoke through the filters were examined by changing the number of bilayers of the films. For this experiment PAH/PAA self-assembly films were formed on the surface of fiber glass clothes with the mass ratio of 133/67. The number of the bilayers are 0, 60, 90, and 120, respectively. In this case, the PAH/PAA films formed at the pH condition of 5.0/5.0 was used as the smoke sensor. The results are shown in Fig.6. As is shown, the performance as the smoke filter increased as the increase of the number of bilayers. When the 120 bilyaers of the films were

deposited on the surface of the fiber glass cloth, the quantity of smoke through the filter decreased to approximately 12% of the case of bare fiber glass cloth. Recently we have found that this value was decreased down to 5% by using strong base as polycation. The details will be published shortly.

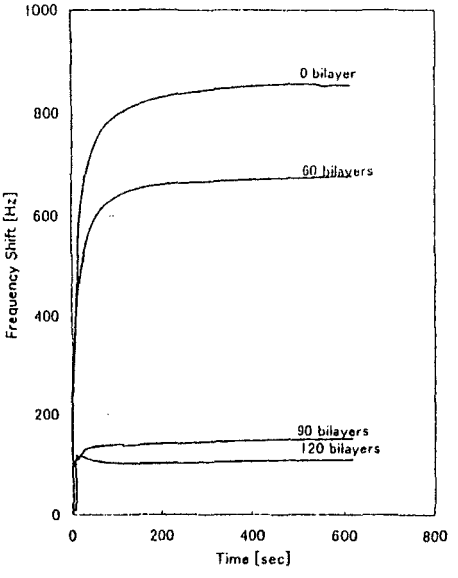

Fig.6 Change of filter performance as the function of the number of bilayers

4. Conclusions

We have demonstrated the high performance characteristics of the thin polymer film formed by the mass-controlled layer-by-layer adsorption of polyelectrolytes films as filter for air cleaner. The adsorption characteristics of smoke to the filter membrane can be optimized by changing the deposition condition such as pH of the adsorption bath, the number of bilayers of the films or the charge density in the polymer films. The filter for smoke can be cleaned just by rinsing with hot water at 90℃. It was confirmed that the filter can be used at least 20 times. Consequently, these thin polymer film can be used as the new type of high performance filter for air cleaner which have a remarkable adsorption characteristics for smoke even without applying power supply to the filter.

Acknowledgements

The authors would like to express sincere thank to prof.M.F. Rubner of and Dr. Michael F. Durstock (US air force research Lab. at present) of Massachusetts Institute of Technology, USA, for the guidance on the layer-by-layer sequential adsorption process of polyelectrolytes. The authors thank prof.Keisuke Shimizu of the Intelectual Property Center of Keio University for the important advice on this study. A part of this work is supported by Kurata foundation(1999), the financial aid from Tokyo Electric Power Company(1999) and research support from Fukuzawa foundation of Keio Univ. and department of applied physics and physico-informatics.

References

[1] Dongsik Yoo, Seimei S.Shiratori, and Michael F.Rubner, Macromolecules, Vol.31,No.13, p.4309-4318.

[2] S.S.Shiratori and M.Yamada, Langmuir-Blodgett Films Workshop, Maui, Hawaii, February 18-20 ,1999,USA.

[3] Japanese PAT Application No.10-10-267286/1998., No.11-077553,No.11-077554., PCT/JP99/04432.

[4] Seimei S. Shiratori and M.F.Rubner , "Nano-scale Control of Selfassembled Ultra-thin Film by in-situ Monitored QCM during Automatic Layer-by-layer Adsorption of Polyelectrolyte" , MRS 1998 Fall Meeting , November 30 – December 4 , Boston MA , USA.

[5] M.Yamada and Seimei S. Shiratori, Transducer 99, LN10, June 7-10,Sendai, Japan,1999.:The digest of technical paers Vol.2. p.1880-1881.

[6] M.Yamada,and S.S.Shiratori submitted in Sensors & Actuators B.

[7] Seimei S.Shiratori, Masayoshi Yamada, International Conference of Science and Technologyies of Advanced polymers, ICAP-99, Abstracts. p.158-159.

[8] Masayoshi Yamada, Seimei S.Shiratori, International Conference of Science and Technologyies of Advanced polymers, ICAP-99, Abstracts. p.102-103..

[9] Seimei S.Shiratori and M.F.Rubner, to be published