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Adsorption Property of UV-cured Films Containing Disulfide Bonds in Water

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Abstract

Disulfide bond-containing polymer films were fabricated in a radical UV curing process to adsorb metal cations or proteins. Bi-functional methacryl monomers having a disulfide bond were designed and used for the UV curing. Resulting films showed practical pencil-hardness, H to 3H, with 1 J/cm² of irradiation at a wavelength of 365 nm. It was confirmed that disulfide bond-containing films adsorbed colored metal cations such as gold(III) and copper(II) cations. During adsorption experiments, disulfide bond-containing polymer films were not detached from a glass substrate, probably due to relaxation of internal stress by bond exchange reactions between disulfide bonds. Bovine serum albumin seemed to be also adsorbed toward films only in the case that the film had ionic moieties.

Keywords : Adsorption, UV-cured film, Disulfide bond, Radical UV curing, Methacryl monomer

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1. Introduction

Separation technology plays quite important role for sustainable chemical industries and our healthful daily lives. Wastewater must undergo removal treatments of various kinds of pollutants, before streaming into rivers and seas. Pesticides are one of major pollutants, and organic dye has been used as a model compound in researches of adsorbents. It was reported that such compounds were adsorbed by clays¹⁾ and metal-organic frameworks (MOFs),²⁾ while these materials could not adsorb high-molecular-weight molecules due to adsorption sites in angstrom scale. Adsorbents for proteins (up to several dozen nm) and viruses (several dozen to hundred nm) would be desired.

Heavy metal cations are also representative as inorganic pollutants, and their adsorbents have been developed by using inorganic carriers such as mesoporous silica,³⁾ iron tailings,⁴⁾ graphene oxide,⁵⁾ and MOFs.⁶⁾ Furthermore, abundant organic carrier materials have been used, including pectin-based⁷⁾ and polysaccharide-based adsorbents.⁸⁾ Inherent carboxy and hydroxy groups in the materials would capture metal cations. Nitrogen-containing moieties would also contribute to the entrapment, while Sulfur-containing ones were not in the limelight. Sulfur moieties are known to work as soft base, and they interact strongly with soft acids including several heavy metal cations. Nakayama reported that mercury(II) and silver(I) cations were adsorbed by interaction with disulfide (SS) bonds in the interlayer space of magnesium–aluminum layered double hydroxide materials.⁹⁾ In this case, however, there is a limit of retention ratio of SS bonds to the carrier. On the other hand, organic polymer materials containing SS bonds have been developed in our group as photo-adhesive materials.¹⁰⁻¹²⁾ It was found that SS bonds would contribute to strong adhesion toward metal substrates. In this article, we have tried to fabricate organic polymer UV-cured films which contain SS bonds at high density (**Fig 1**), for using as an

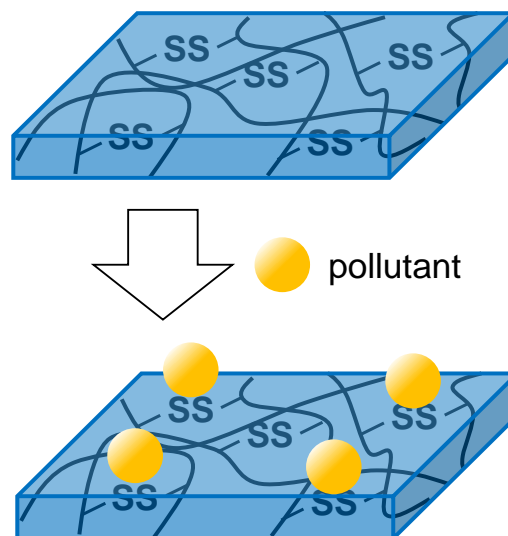


Fig 1. Adsorption of pollutants such as heavy-metal cations and proteins by interaction with disulfide (SS) bonds in a UV-cured film.

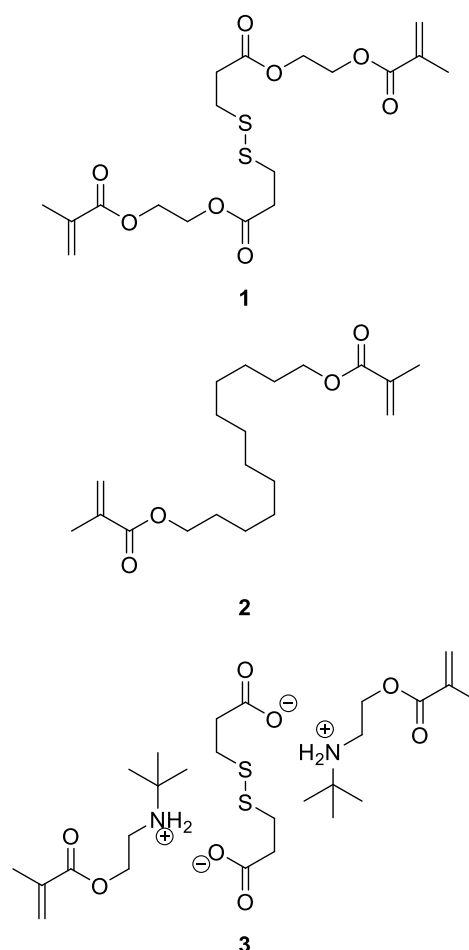


Fig 2. Chemical structures of bi-functional methacryl monomers having a disulfide bond (**1**, **3**), and a control monomer **2**.

adsorbent of heavy metal cations and proteins. Gold(III) and copper(II) cations were chosen in our study, because visual observation could be conducted easily. Furthermore, adsorption of a protein was examined with our UV-cured films. SS bonds in a protein work for structural stability of its tertiary structure.¹³⁾ It was expected that proteins were fixed through exchange reactions between SS bonds¹⁴⁾ on the film surface “open space”. Bi-functional methacryl monomers (monomers **1** and **3**, **Fig 2**) having a SS bond were prepared and used in radical UV curing.

2. Experimental

2.1 Materials and Equipment

3,3'-Dithiopropionic acid, 2-hydroxyethyl methacrylate (HEMA), 2-(*tert*-butylamino)ethyl methacrylate (*t*BuAEMA), 1,12-dodecanediol dimethacrylate (monomer **2**), and Omnirad819 (phenylbis(2,4,6-trimethylbenzoyl) phosphine oxide) were purchased from Tokyo Chemical Industry Co., Ltd. (Tokyo, Japan). Chloroform (CHCl₃) and acetone were purchased from NACALAI TESQUE, Inc. (Kyoto, Japan). Dichloromethane (DCM), sodium tetrachloroaurate (NaAuCl₄, dihydrate), copper(II) chloride (CuCl₂, dihydrate), and chloroform-*d* (CDCl₃) were purchased from FUJIFILM Wako Pure Chemical Corporation (Osaka, Japan). Bovine serum albumin (BSA, IgG-free, protease-free) was purchased from Jackson ImmunoResearch Laboratories, Inc. (Pennsylvania, USA). All chemicals were used without further purification.

¹H- and ¹³C-NMR spectra were recorded using a Bruker AVANCE III. ATR-IR spectral measurements were performed using a Perkin Elmer Spectrum100. Radical UV curing was performed with 3UVTM-36UVLamp (Analytik Jena AG) and UIT-250/UVDC365 ultraviolet radiometer (Ushio Inc.). Pencil-hardness of the UV-cured films was evaluated with MJ-PHT tester (SATO SHO-JI Corporation). Static water contact angle of films was measured using an SImage Entry 6 (Excimer Inc.).

2.2 Monomers

Bi-functional methacryl monomer **1** was synthesized from 3,3'-dithiopropionic acid and HEMA as starting compounds in a 21% yield. The synthetic procedure was described elsewhere.¹⁵⁾ Monomer **3** was prepared as follows.

*t*BuAEMA (0.89 g, 4.8 mmol) in DCM (10 mL) was dropped to 3,3'-dithiopropionic acid (0.50 g, 2.4 mmol) in DCM (10 mL), and the solution was stirred under nitrogen atmosphere at room temperature for 178 h. After evaporating, **3** was obtained in a 95% yield as a white solid. ¹H-NMR (400 MHz, CDCl₃): δ 1.29 (18H, s, -C(CH₃)₃), 1.96 (6H, s, -CH₃), 2.64 (4H, m, -CH₂CH₂-O-), 2.95 (4H, m, -CH₂CH₂-O-), 3.09 (4H, m, -CH₂CH₂-S-), 4.41 (4H, m, -CH₂CH₂-S-), 5.62 (2H, m, =CH₂), 6.17 (2H, m, =CH₂), 7.96 (4H, br, -N⁺H₂-). ¹³C-NMR (100 MHz, CDCl₃): δ 18, 27, 35, 37, 40, 54, 62, 126, 136, 167, 177.

2.3 Fabrication of UV-cured films

Glass substrates were ultrasonicated with acetone and then CHCl₃. Films were fabricated by following two methods.

Bar-coat method was used to prepare film samples for adsorption of heavy metal cations. To bi-functional methacryl monomers **1-3** were added HEMA (300-600 mol%), Omnirad819 (4-13 wt% toward monomers), and at least amount of solvent (THF for **1** and **2**, CHCl₃ for **3**). Each solution was bar-coated on a glass substrate (4 mil = 101.6 μ m in thickness). Films were subjected to UV irradiation (1.5 mW/cm², 1 J/cm²) at a wavelength of 365 nm.

On the other hand, drop-cast method was used to prepare film samples for adsorption of BSA protein. To bi-functional methacryl monomers **1-3** were added HEMA (*ca.* 2500 mol%), Omnirad819 (7 wt% toward monomers), and at least amount of CHCl₃. Each solution was drop-cast on a glass substrate. Films were subjected to UV irradiation (1.5 mW/cm², 1 J/cm²) at a wavelength of 365 nm.

2.4 Adsorption of heavy metal cations

Following the procedure of bar-coat method in section 2.3, UV-cured films were fabricated with monomer **1** and **2**. Resulting films were named as **Film-1** and **Film-2**. These film samples were immersed into 30 mM of NaAuCl₄ or CuCl₂ aqueous solution at room temperature. After 1, 3, 5, and 60 min, films were taken out and washed with distilled water. Air dried film samples were then subjected to visual observation (for Au³⁺ and Cu²⁺ cations), or color image analysis (for Au³⁺ cation).

Color image analysis was conducted by using arbitrary nine pixels for each film image (0, 1, 3, 5 min for **Film-1**, and 0, 1, 3, 5 min for **Film-2**). One pixel was at center of film in the image, and others were within the radius of 60 px from the center pixel. A film in an image was a square, *ca.* 150-210 px each side. Each pixel had a set of standard RGB decimal values, *e.g.* yellow: **Y** (R, G, B) = (255, 255, 0). These values were converted to their ratios r, g and b by equations below,

$$r = \frac{R}{R + G + B}$$

$$g = \frac{G}{R + G + B}$$

$$b = \frac{B}{R + G + B}$$

Values (r, g, b) of representative five colors were calculated as follows, yellow: **Y** (0.5, 0.5, 0), red: **R** (1, 0, 0), green: **G** (0, 1, 0), blue: **B** (0, 0, 1), and white-to-gray: **WG** (0.333, 0.333, 0.333). These five points were plotted in an r - g plane as a projection view (**Fig 3**). Total nine sets of (r, g) were also plotted in a plane for each film image, to show graphically time course of color of each film sample during immersion in Au³⁺ aqueous solution. All sets were plotted in the range of $0.323 < r < 0.343$ and $0.323 < g < 0.343$.

2.5 Adsorption of BSA protein

Following the procedure of drop-cast method in

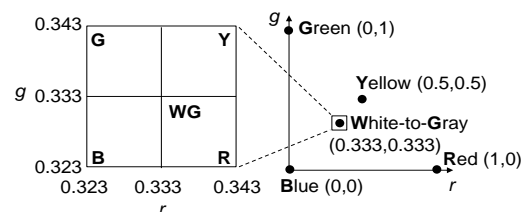


Fig 3. Five representative colors; yellow: **Y**, red: **R**, green: **G**, blue: **B**, and white-to-gray: **WG** in r - g plane that is for color image analysis in this study.

section 2.3, UV-cured films were fabricated with monomers **1, 2** and **3**. Resulting films were named as **Film-I, Film-II** and **Film-III**. These film samples were immersed into 7.9 μ M of BSA aqueous solution at room temperature. After 60 min, films were taken out and washed with distilled water. Air dried film samples were then subjected to ATR-IR spectral measurements.

3. Results and Discussion

3.1 Fabrication of UV-cured films

Table 1 and **Table 2** show the values of pencil-hardness of UV-cured films. In bar-coat method, the weight ratio of monomer/HEMA was fixed to 1/1

Table 1. Pencil-hardness of UV-cured films fabricated in bar-coat method using monomers **1-3**. **Film-1** and **Film-2** were used for adsorption of heavy metal cations.

Entry	Monomers (mol/mol) ^a	Pencil-hardness
1	1 /HEMA (1/4)	H (Film-1)
2	2 /HEMA (1/3)	2H (Film-2)
3	3 /HEMA (1/6)	Liq.
4 ^b		< 6B

^aBi-functional methacryl monomer/HEMA = 1/1, w/w.
^b2.9 mW/cm², 15 J/cm².

Table 2. Pencil-hardness of UV-cured films fabricated in drop-cast method using monomers **1-3**. **Film-I, Film-II** and **Film-III** were used for adsorption of BSA protein.

Entry	Monomers (mol/mol)	Pencil-hardness
1	1 /HEMA (1/24)	2H (Film-I)
2	2 /HEMA (1/25)	H (Film-II)
3	3 /HEMA (1/27)	3H (Film-III)

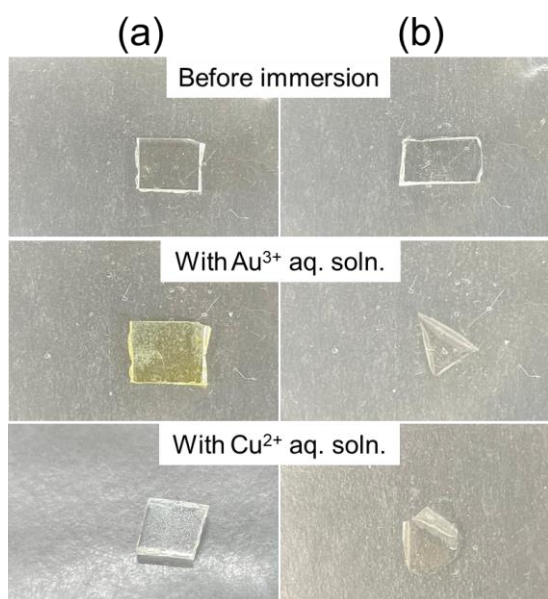


Fig 4. Photographs of UV-cured films (a) **Film-1** and (b) **Film-2**, before immersion (upper), after immersion into 30 mM of Au³⁺ (middle) or Cu²⁺ (bottom) aqueous solution at room temperature for 60 min.

(see annotation below the Table). In the evaluation of physical property of films, the hardness of pencil is arranged as follows: 6B (softest), 5B, 4B, 3B, 2B, B, HB, F, H, 2H, 3H, 4H, 5H, 6H (hardest). Practical pencil-hardness was recorded in cases of **Film-1** (2H) and **Film-2** (H). Static water contact angles of **Film-1** and **Film-2** were 83° and 85°, respectively. Films were more hydrophobic than a glass substrate (32°).¹²⁾ Films was not cured with monomer **3** under the same condition. Even increasing both intensity (2.9 mW/cm²) and irradiation energy (up to 15 J/cm²), the pencil-hardness was less than 6B. Monomer **3** had ionic bonds which could be exchanged readily even in a UV-cured film if the density was high, resulting in softening the film surface.

In drop-cast method, the molar ratio of monomer/HEMA was fixed to *ca.* 1/25, decreasing the density of monomers **1-3** (monomer/HEMA = 1/6 to 1/10, w/w). UV-cured films **Film-I**, **Film-II**

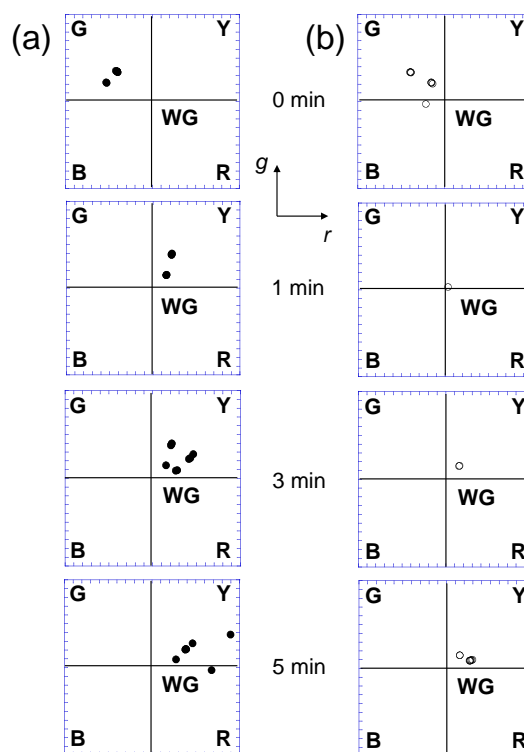


Fig 5. Time course of color of film samples (a) **Film-1** and (b) **Film-2** during immersion into 30 mM of Au³⁺ aqueous solution at room temperature. Longitudinal axis: g , $0.323 \leq g \leq 0.343$, horizontal axis: r , $0.323 \leq r \leq 0.343$. Nine sets of (r, g) are plotted in each r - g plane.

and **Film-III** were fabricated successfully to obtain H to 3H of pencil-hardness.

3.2 Adsorption of heavy metal cations

Both films were transparent before immersion into aqueous solution of heavy metal cations. As shown in **Fig 4(a)**, color of **Film-1** became yellow after immersion in Au³⁺ aqueous solution, comparing with color of **Film-2** (**Fig 4(b)**). This indicated adsorption of Au³⁺ cations through interaction with SS bonds. Although such color change was not observed in the case of Cu²⁺ aqueous solution, there was a clear difference between two films where **Film-1** became opaque.

Fig 5(a) showed that color of **Film-1** was changed from cool color to warm one, like pale yellow, within 1 min. Color change was observed in the case of **Film-2**, while the variation range was small (**Fig 5(b)**). **Film-2** was detached from the glass substrate during immersion experiments. Furthermore, it seemed that color dispersion of **Film-1** was larger

than of **Film-2**. This could indicate non-uniformity of the surface in microscopic level. Indeed, **Film-1** after immersion into Au^{3+} and Cu^{2+} aqueous solution, ruggedness was observed visually in **Fig 4**. Adsorption of heavy metal cations would change film surface profiles dynamically, probably due to cross-linking between cations and SS bonds, and swelling with water.

Films were fabricated in a radical process, which was accompanied with film-shrinking.¹⁶⁾ Resulting UV-cured films on a substrate would hold somewhat internal stress (**Fig 6**). In the case of **Film-1** having SS bonds, exchange reactions between SS bonds would be induced by internal stress (**Fig 6(a)**).¹⁷⁾ Consequently, internal stress was relaxed, resulting in remaining cross-linked polymer networks on a substrate. On the other hand, in the case of **Film-2** having no SS bonds, internal stress was not relaxed (**Fig 6(b)**). Stress concentration at the film-substrate interface would result in film-detachment. It was considered that SS bonds in UV-cured films would work for not only adsorption but also fixation of a film on a substrate.

3.3 Adsorption of BSA protein

Film-detachment from glass substrate was not observed in all film samples, even in the case of **Film-II**, after immersion for 60 min. It would result from low-crosslinking density, comparing with the case of **Film-2**. In ATR-IR spectra, intensity of two peaks around 1640 cm^{-1} and 1550 cm^{-1} seemed to increase after the immersion, only in case of **Film-III** (**Fig 7**). These peaks could be assigned to amide I and II bands of secondary acyclic amide compounds.¹⁸⁾ This could be an evidence that BSA proteins were adsorbed on **Film-III**. Such spectral change was not observed in cases of **Film-I** and **Film-II**. These results indicate that BSA proteins would interact electrostatically with ionic moieties rather than SS bonds.

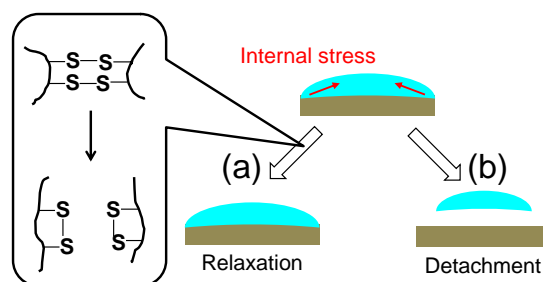


Fig 6. A possible mechanism of (a) film-remaining in cases of **Film-1**, and (b) film-detaching in cases of **Film-2**, during immersion.

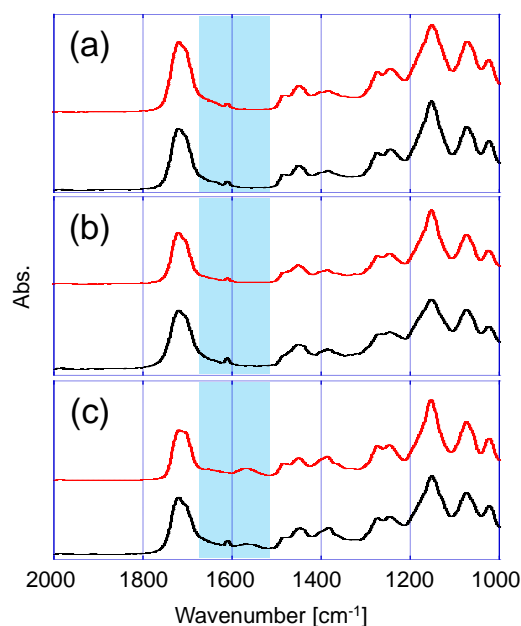


Fig 7. ATR-IR spectral changes of (a) **Film-I**, (b) **Film-II** and (c) **Film-III**. Upper and lower spectra are recorded after and before immersion into $7.9\ \mu\text{M}$ of BSA protein aqueous solution, respectively.

4. Conclusion

UV-cured films were fabricated successfully by using bi-functional methacryl monomers having a SS bond. In adsorption experiments of heavy metal cations, it was found that SS bonds would interact with such cations and that SS bonds could dissipate internal stress through exchange reactions among themselves. Furthermore, UV-cured films having ionic moieties could adsorb proteins probably due to electrostatic interaction. Our SS bond-containing organic polymer material will be a powerful candidate of absorbents. UV coating toward various kinds of substrates and adsorbing ability of the materials are now under investigation.

Acknowledgement

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2023 年度 材料技術研究協会 討論会報告

討論会委員会委員長 酒井 秀樹 (東京理科大学)

討論会実行委員長 羽田 宣弘 (環太平洋大学)

2023 年 12 月 1 日 (金)、2 日 (土) の 2 日間、2023 年度 材料技術研究協会討論会が東京理科大学神楽坂キャンパス森戸記念館で開催されました。年末のお忙しい時期に討論会で発表していただいた方々、参加いただいた方々、また討論会運営にご支援をいただいた方々に心よりお礼申し上げます。

本年度の討論会も昨年と同様、対面を基本として一部来場が困難な方に対してオンラインを併用する形をとることになりました。また、Covid-19 の流行後はじめて懇親会を開催することができ、参加者どうしの交流を深めることができました。

討論会 1 日目 (12 月 1 日)

A、B 両会場での討論会委員長・副委員長による開会挨拶の後、9 時 30 分から口頭セッションが始まりました。各会場において最新の成果に関する発表と活発な質疑が行われました。

また、A 会場では、10 時から 2 件の学生論文賞受賞講演が実施されました。1 件目は、東京学芸大学

・塚崎 舞先生による「布上でのタンパク質直接定量に及ぼす布帛種の影響」、2 件目は、実践女子大学・小川裕耶先生による「寒天ゲル内への染料の浸透に及ぼす寒天濃度、染料濃度、染料分子構造の影響」の講演でした。両先生とも博士課程修了後にアカデミックポジションで活躍されています。

続いて 10 時 40 分からは、昨年に続いて「環境・エネルギー研究部会シンポジウム」が開催され、お二人のフロントランナーの先生による特別講演が行われました。

・小野澤伸子先生 (産業技術総合研究所)

「ペロブスカイト型太陽電池の研究開発最前線」

・辻口拓也先生 (金沢大理工)

「CCU に貢献するエネルギーキャリア「ギ酸」

当該分野の先端の研究を展開されている先生方のご講演は、関連分野のみならず他分野の聴講者にとってもインパクトがある素晴らしい講演でした。

昼食を挟んで午後からは、本協会会長の鈴木 昇先生 (宇都宮大学名誉教授) による総合講演が、「粉体の表面改質と評価法」のタイトルで行われました。粉体の表面の制御法について、その基礎から実際の応用事例まで分かりやすい講演が行われ、また講演スライドを聴講者がダウンロードできるようご配慮いただき、



図 1 鈴木 昇会長による総合講演の様子



図 2 小石眞純賞を受賞された堀越智先生の表彰式

学生にのみならず我々研究者も大変勉強させていただきました。

総合講演に引き続き、令和5年度「小石眞純賞」受賞者である 堀越 智先生（上智大学 物質生命理工学科）による受賞講演が、「マイクロ波サイエンスの研究」のタイトルで行われました。堀越先生のマイクロ波に関するこれまでのオリジナリティーに溢れる研究、そしてその成果が広範な分野に応用されていることに感銘を受けました。

その後、A、B2会場の平行セッションにシフトし、A会場では、昨年同様「表面改質部会 特別セッション」が開催され、以下4件の依頼講演が行われました。

・矢野慧一先生（清水建設株式会社）

「DAC コート：コンクリートの表面コーティングによるCO₂固定促進技術」

・武藤浩行先生（豊橋技術科学大学）

「静電相互作用を利用した原料粒子の集積技術」

・小島綾太先生（綜研化学株式会社）

「マイカ複合粉体の開発」

・土屋博之先生（AGC株式会社 材料融合研究所）

「ソーダライムガラス中のFe²⁺イオンの構造と着色」

その後、A会場では、「表面改質部会 特別セッション」および「環境・エネルギー研究部会シンポジウム」の一般講演が行われ、幅広い分野からの話題提供が行われました。並行してB会場では、主に生体材料分野の一般口頭講演が実施され、活発な質疑応答が行



図3 懇親会での歓談の様子

われました。

A、B両会場の口頭セッション修了後、18時30分から東京理科大学神楽坂キャンパス内の食堂で懇親会が開催されました。久しぶりのアルコールを交えながらの懇親会で、学生を含む参加者の交流が図られ、大変盛況のうちに終了することができました。

討論会2日目（12月2日）

討論会2日目の朝のセッションではA、B2会場において、「表面・界面」ならびに「無機材料」に関する口頭講演が行われました。

その後10時40分からは、産学から2名の先生による「特別講演」が実施され、活発な質疑応答が行われました。

・長谷川裕之先生（島根大学教育学部）

「インクジェットパターンニングによる視覚機能を模倣したセンサー技術」

・柿澤 恭史先生（ライオン（株）・先進解析科学研究所）

「感染症に悩まない世界の実現に向けて ～カチオン界面活性剤のウイルス不活化効果を増強する技術～」

昼食を挟んで13時15分からは、ポスター発表が行われました。昨年よりも多い32件のポスター発表に対して、大変活気のある質疑・応答が行われ、発表者の方、特にこれまで対面で発表する機会が限られていた学生の皆さんにとっては、貴重な議論ができたこと



図4 ポスターセッションの様子

もに、学外の研究者・学生と交流を深めるとても意義のある経験となったのではないかと思います。

ポスターセッション終了後、討論会は盛況裏のうちに閉会となりました。

本討論会の開催は、非常に多くの方々のご尽力により可能となりました。討論会 HP の管理や要旨集のアップロードは長谷川裕之副実行委員長と事務局のご尽力により円滑に行われました。また、討論会の当日運営については、討論会委員の先生方を中心に円滑に行われ、山内仁史専務理事には財政面でのアドバイスを多くいただきました。また、多くの先生方には、座長や賞の審査などご協力いただき心よりお礼申し上げます。

さらに、下記の方々から、討論会運営に協賛金、ご寄付の形で多大なご支援をいただきました。心よりお礼申し上げます。(敬称略、50音順)

エムディジャパン株式会社□

株式会社 L.V.M.C.

小石真純 (材料技術研究協会 □ 名誉会長) □

小浦節子 (材料技術研究協会 □ 前会長) □

HTL 株式会社

材料技術研究協会 □ 表面改質研究会 □

株式会社 □ ジェイテクト □

株式会社細川洋行 □

ユニ・チャーム株式会社 □

口頭講演賞・ポスター賞について

口頭講演・ポスター発表について、複数審査員による審査を実施し、特に優れた講演について、優秀口頭講演賞、ゴールドポスター賞、シルバーポスター賞を選考いたしました。以下に優秀口頭講演賞、ゴールドポスター賞の受賞者(発表者)を記載させていただきます。

優秀口頭講演賞受賞者 (12件) (敬称略)

1A-01 Fe₃O₄ アノード触媒を用いた堆積物微生物燃料電池の発電特性 (千葉工業大学院工) 根立拓郎

1B-01 燃料電池触媒担体への応用に向けたケッチェンブラックの表面改質 (東理大創域理工) 秋山礼奈

1B-04 銅配線のマイクロ波被覆材熱分解法に関する基礎研究 (上智大理工) 蜂須賀直樹

1A-06 塩化マグネシウムを用いた球状炭酸カルシウムの合成 (日大理工) 向後光亨

1B-08 核内移行性を示すポルフィリン誘導体の創製と光増感剤としての有用性評価
(東理大院創域理工) 早川夏海

1B-09 がん治療を目的としたポルフィリン- ω 3 脂肪酸複合体の細胞内挙動の解明 (東理大院創域理工) 伊藤謙志

1B-11 リン脂質/コレステロール混合リポソームの形態に及ぼす胆汁酸塩添加の影響 (東理大創域理工) 小田真稔

1B-15 油/水界面膜の粘弾性挙動に及ぼす油種の影響 (東理大創域理工) 栗原宏樹

2A-01 脂肪酸薄膜の界面活性剤水溶液による剥離機構の考察 (東理大創域理工) 齋木夏鈴

2A-02 冷凍機油用リン系摩耗防止剤の吸着特性
(東理大創域理工) 湯浅大海

2A-04 トリメチルシリル基を親 CO₂ 基としたノニオン性界面活性剤の水/超臨界 CO₂ 混合系における界面物性と会合挙動 (弘前大院理工) 飯塚大登

2B-02 ZnO/TiO₂ 複合粒子の調製およびその固体酸触媒特性 (千葉工大工) 小野澤彩

ゴールドポスター賞受賞者 (12件) (敬称略)-

P-01 バクテリオロドプシンを用いた DOG フィルタの作製と特性 (島根大院自然科学研究科) 小玉貴大

- P-02 胆汁酸塩を介した脂溶性物質の膜透過機構の解明（東理大創域理工）小田真稔
- P-04 水性二相系を用いた逆相界面重合法によるマイクロカプセルの調製（新潟大自然）小野瑛史
- P-05 硝酸処理を施した CF 強化 PPS 複合材料のトライボロジー特性に及ぼす雰囲気温度の影響（工学院大院）川合優作
- P-10 アップヒル三重項エネルギー移動で成立するアップコンバージョンシステムにおける半導体ナノ結晶のサーモプラズモニック効果（日大院理工）渡辺理玖
- P-12 イオン性界面活性剤の疎水性水和水の構造の決定（千葉工大）橋本彩奈
- P-15 軟 X 線発光スペクトロスコピーによる撥水性自己組織化材料の分子構造と水の相互作用解析（東大院新領域）富依勇佑
- P-16 単層カーボンナノチューブの捻りにより誘発される化学反応（公立諏訪東京理科大学工学・マネジメント研究科）油本圭市
- P-17 その場観察 AFM 法を用いた硫黄系極圧剤の摩耗防止機構の解明（東理大創域理工）藤田晃徳
- P-19 リチウムイオンバッテリーのサイクル寿命改善を目指したリン添加及び鉄被覆シリコンナノ多孔粒子負極の開発（東京電機大）立花孝通
- P-22 赤外レーザー蒸着法による LiH エピタキシャル薄膜合成と元素置換（芝浦工大院理工）宗房幸太
- P-27 堆積物微生物燃料電池における過電圧の要因解析（千葉工大工）高橋悦子

編集後記

Volume 41 の最終号(2023 年, Volume 41, No. 6)を公開いたします。2022 年(Volume 40)より, 協会ウェブと J-stage の両方のプラットフォームで記事を公開してまいりましたが, 2024 年(Volume 42)からは, J-stage のみでの公開に移行します(会員の皆さまには, 当初, Volume 41 から J-stage のみの公開となるとお伝えしておりましたが, 諸事情で Volume 41 の全号を両者での公開を継続しました)。本誌は J-stage の以下の URL で公開しております。オープンアクセスとなり, 記事に DOI が振られ, 引用文献からのリンクが張られる等, サーキュレーション, 利便性が高まっております。また, 年度ごとの統合版(印刷版)の発刊は継続致しますし, これまで通り別刷りの印刷も承ります。奮ってご投稿いただけますようお願い申し上げます。

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(浜松医科大学 三浦康弘)



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