Effect of Hydrogen Sulfide Ions on the Passive Behavior of Type 316L Stainless Steel

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Corrosion resistance of stainless steel is thought to be dependent on degradation of the passive film, which is important to understand a precursor process involved in localized corrosion such as pitting corrosion and to estimate the long-term performance of the material. Inclusions of sulfides such as manganese sulfide (MnS) are known to provide pitting corrosion sites of stainless steel.1–3 As for the roles of MnS in pitting corrosion, it has been generally agreed that electrochemical and/or chemical reactions of MnS release S species (SO4 2−, HSO3 −, S2O3 2−, S 2−, and S 2−). The released S species change the composition of the local solution contiguous to the inclusion and lead to a decrease of pH near the micro-area. The decrease in pH and the presence of aggressive S species result in transition of the passive surface to a transpassive state, causing exposure of the substrate to the solution, which is the initiation of pitting corrosion.1–3 Eklund suggested that the dissolution of MnS gives rise to acidification of the solution by producing sulfate ions:1

\[
\text{MnS} + 2\text{H}^+ = \text{Mn}^{2+} + \text{H}_2\text{S} \quad [2]
\]

Many possible explanations for the detrimental effects of various S species causing initiation and/or propagation of pitting corrosion on stainless steel have been presented. Most previous studies have focused on the overall processes, including destabilization of the passive film, removal of the film, and initiation and/or propagation of pits. Since degradation of the passive film is the initial process of pitting corrosion, it is important to contemplate the change in passivity or passive film until depassivation.

When stainless steel is exposed to an aqueous solution, a small amount of MnS on the stainless steel surface dissolves because its solubility in water is 4.7 ppm at 291 K.5

\[
\text{MnS} + 2\text{H}^+ = \text{Mn}^{2+} + \text{H}_2\text{S} \quad \text{(in acidic solution)} \quad [2]
\]

Furthermore, the dissociations of H2S and HS − in aqueous solutions are as follows:

\[
\text{H}_2\text{S} = \text{HS}^- + \text{H}^+ \quad [10]
\]

\[
\text{HS}^- = \text{S}^{2-} + \text{H}^+ \quad [11]
\]

The values of pKa for Eqs. 10 and 11 are 7.05 and 19.0, respectively, at 298 K.7 The dissociation of HS − is negligibly small and H2S generates mainly protons during its dissociation. Thus, the primary dissolution reaction of MnS momentarily increases pH of the local solution near the MnS. However, little attention has been given to the effect of HS − on the passivity of stainless steel.

The use of a liquid-phase ion gun (LPIG) is a microelectrode technique, a type of scanning electrochemical microscopy (SECM), which is effective for controlling the release of infinitesimal anions to a local space in the solution.9 Recently, we have developed an LPIG to release a ppm-order amount of HS − by cathodic polarization of a silver microelectrode covered with a silver sulfide (Ag2S) layer.7 The total amount of HS − during the operation of the LPIG is in a safe order. It is possible to control the concentration of HS − in the vicinity of the LPIG by its polarization. Application of the LPIG to other metal surfaces is expected to elucidate the mechanism and/or kinetics of depassivation of the stainless steel surface in a solution containing HS −.

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This study is the first study in which the LPIG was applied to type 316L stainless steel as a generator of HS–. The effect of HS– on degradation of the passive film is discussed.

**Experimental**

*Materials.* — Type 316L stainless steel (782560, Nilaco) embedded in epoxy resin with a surface area of 0.07 cm$^2$ was used as a specimen. The procedure for fabrication of the LPIG microelectrode is basically the same as that reported previously. A silver microelectrode was prepared from a silver wire with a purity of 99.9% and a diameter of 500 μm by embedding in a 1 mm diameter glass capillary with epoxy resin. The microelectrode was polarized at –0.7 VSSE in deaerated 0.1 mol dm$^{-3}$ Na$_2$S solution until the electric charge of 10 mC was consumed. A tungsten wire with a purity of 99.9% and silver wire with a purity of 99.9%, both with diameters of 100 μm, were embedded in epoxy resin with a diameter of 25 mm as a substrate for estimating pH and hydrogen sulfide ion concentration [HS–], respectively. A platinum microelectrode with a diameter of 30 μm was used as a tip electrode of an SECM. All electrodes were mechanically ground with SiC papers down to 4000 grit and then rinsed with distilled water.

*Electrochemical setups and conditions.* — Figure 1 shows schematic illustrations of the experimental setups used in this study. In all measurements, an acrylic cell with a solution volume of 100 cm$^3$ was used. A platinum plate was used as a counter electrode, and a silver/silver chloride electrode in contact with KCl-saturated solution was used as a reference electrode. The microelectrode of the LPIG or SECM was positioned above the substrate electrode with an inter-electrode distance of 125 μm or 20 μm using a stepping motor X-Y-Z stage (SGSP20-35, Sigma Koki) and an optical microscope.

Operations of the LPIG were carried out in deaerated pH 8.4 buffer solution (0.15 mol dm$^{-3}$ H$_3$BO$_3$ and 0.15 mol dm$^{-3}$ NaB$_4$O$_7$) with an inter-electrode distance of 125 μm. The LPIG microelectrode was galvanostatically polarized at –3 μA using a battery-driven current source (SS7012, HIOKI). The potential of the LPIG microelectrode was measured by an electrometer (R8240, Advantest). Figure 1a shows an LPIG setup for investigating the passivity of the stainless steel specimen. After immersion for 600 s, the LPIG microelectrode was polarized for 0, 1900, 1950 or 2400 s to generate S species. After the LPIG operation, potentiostatic polarization of the specimen electrode at 0.4 VSSE and following electrochemical impedance spectroscopy (EIS) or Mott-Schottky (M-S) analysis were conducted using a potentiostat (SP-150, Biologic). In EIS, electrode potential was perturbed by ±10 mV in a frequency range from 10$^4$ to 10$^{-1}$ Hz. The M-S analysis was promptly conducted at a frequency of 15 Hz and at a potential of 0.4 VSSE and stepwise-shifted potentials to –0.4 VSSE. A software package (EC lab V, Biologic) was used to fit curves of the impedance data.
On the other hand, for estimating solution pH and/or [HS\textsuperscript{−}] during the LPIG operation, both the tungsten and silver microelectrodes were located as substrates with an interelectrode distance of 125 μm and connected to different electrometers with the same reference electrode (Figure 1b). For the calibration of tungsten microelectrode potential to pH, the following deaerated solutions were used: 0.15 mol dm\textsuperscript{−3} sulfuric acid (pH 0.9), 0.04955 mol dm\textsuperscript{−3} phthalic acid-phthalate buffer (pH 4.0), 0.02489 mol dm\textsuperscript{−3} phosphoric acid-phosphate buffer (pH 6.9), 0.15 mol dm\textsuperscript{−3} boric acid-borate buffer (pH 8.4) and 0.025 mol dm\textsuperscript{−3} sodium hydroxide (pH 10.0). After monitoring the rest potential (Figure 1b). For the calibration of tungsten microelectrode potential and the specimen surface was monitored by SECM in a solution containing 1 × 10\textsuperscript{−3} mol dm\textsuperscript{−3} hydroxymethylferrocene (FcMeOH). Figure 1c shows the SECM setup used in this study. Most of the parts were similar to those used previously by Fushimi.\textsuperscript{10} The platinum tip electrode and specimen substrate electrode were connected to a bipotentiostat (HAL-1512 mM2, Hokuto Denko) and polarized independently at $E_1 = 0.6$ V\textsubscript{SSE} and $E_0 = −0.2$ V\textsubscript{SSE}, respectively, for a tip generation/substrate collection (TG/SC) mode. Simultaneously, the tip microelectrode was scanned in an area of 3000 μm square with stepwise of $dx = 30$ μm and $dy = 30$ μm, respectively, and intermissions of 0.5 s and 5 s, respectively, with an interelectrode distance of 20 μm.

Surface analysis.— The surface of the stainless steel specimen was analyzed by an Auger electron spectroscopy (AES; JAMP-9500F, JEOL) with an electron beam (10 keV, 15 nA). $Ar^+$ sputtering at an etching rate of 3.2 nm min\textsuperscript{−1} equivalent to silica was used for obtaining a depth profile of the local specimen surface with an electron beam diameter of 30 μm. In all experimental tests, consistency was confirmed more than 3 times by repetition with different specimens under the same conditions.

Results

Estimation of pH and [HS\textsuperscript{−}] during LPIG operation.— Figure 2 shows the electrode potential of the tungsten microelectrode as a function of solution pH. It is obvious that the potential and pH have a linear relation:

$$E / V_{SSE} = 0.0990 - 0.04685 \text{pH}. \quad [12]$$

The slope is almost in agreement with that reported when a tungsten microelectrode with a diameter of 25 μm was used to estimate various pH values.\textsuperscript{31} In this study, the pH value in the interelectrode space during the LPIG operation was estimated by Eq. 12.

![Figure 2](image)

Figure 2. Electrode potential of the tungsten microelectrode of the substrate as a function of solution pH.

Figure 3 shows changes in electrode potentials of the LPIG microelectrode $E_{\text{LPIG}}$, tungsten microelectrode $E_W$, and silver microelectrode $E_{\text{Ag}}$ before and after the LPIG was galvanostatically polarized at $−3$ μA. The value of pH and [HS\textsuperscript{−}] were estimated using Eqs. 12 and 14.

![Figure 3](image)

Figure 3. Changes in electrode potentials of the LPIG microelectrode $E_{\text{LPIG}}$, tungsten microelectrode $E_W$, and silver microelectrode $E_{\text{Ag}}$ before and after the LPIG was galvanostatically polarized at $−3$ μA. The value of pH and [HS\textsuperscript{−}] were estimated using Eqs. 12 and 14.

The equilibrium potential of Eq. 13 is a function of pH and [HS\textsuperscript{−}] as follows:

$$E / V_{SSE} = -0.274 - 0.0295 \text{pH} - 0.0295 \log[\text{HS}^\text{−}]. \quad [14]$$

The reduction of Ag\textsubscript{2}S increases pH as well as [HS\textsuperscript{−}]. The value of pH, converted from Eq. 12 by substituting the value of $E_W$, of the solution is sustained at ca. 8.5 before polarization of the LPIG. However, pH rapidly reaches a constant value of ca. 9.5 after the onset of polarization, and this value is sustained during the polarization. This means that local alkalization in the vicinity of the tungsten microelectrode is in a steady state. It is thought that the mass of OH\textsuperscript{−} generated from the LPIG microelectrode is balanced between the interelectrode space and bulk solution. During the local alkalization, hydrogen gas did not evolve on the LPIG, whereas $E_{\text{LPIG}}$ was sustained at $−0.7$ V\textsubscript{SSE}. On the other hand, it is possible to estimate the value of [HS\textsuperscript{−}] by substituting the values of pH and $E_{\text{Ag}}$ into Eq. 14. When the LPIG was polarized cathodically, [HS\textsuperscript{−}] reached ca. $1.5 \times 10\textsuperscript{−3}$ mol dm\textsuperscript{−3} within 100 s and then gradually increased and reached ca. $4.0 \times 10\textsuperscript{−3}$ mol dm\textsuperscript{−3} of 2400 s. When the polarization of the LPIG microelectrode was stopped and the LPIG microelectrode was pulled up to the bulk solution, the values of pH and [HS\textsuperscript{−}] immediately decreased, suggesting that the products, OH\textsuperscript{−} and HS\textsuperscript{−}, in the interelectrode space are diluted. The space is so small that products from the LPIG accumulated and the buffering effect of the solution did not act effectively to keep the pH in the space.

Nevertheless, the operation of the LPIG microelectrode is useful for concentrating HS\textsuperscript{−} in the local space of the substrate. The concentration of HS\textsuperscript{−} in the narrow space between the electrodes can be
Figure 4. Potentiodynamic polarization curve of type 316L stainless steel at a scan rate of 1 mV s⁻¹ in a deaerated pH 8.4 boric-borate buffer solution.

Figure 5. Changes in electrode potentials $E_{\text{LPIG}}$ and $E_{\text{316L}}$ of the LPIG microelectrode and stainless steel substrate electrode, respectively, before and after the LPIG operation to accumulate HS⁻ in the interelectrode space at (a) 0.0, (b) 1.5, (c) 2.2 or (d) $2.8 \times 10^{-3}$ mol dm⁻³.
Before the LPIG operation, \( E_{\text{LPIG}} \) does not shift, whereas \( E_{316L} \) shifts to a positive potential. This means that the LPIG is relatively stable without releasing HS\(^-\). The stainless steel surface is in a passive state and the passivity seems to be gradually improved. When the LPIG microelectrode is cathodically polarized, i.e., in an LPIG operation, however, \( E_{\text{LPIG}} \) immediately shifts to \(-0.7\) V\( _{\text{SSE}} \), indicating that Ag\(_2\)S is reduced and generates OH\(^-\) and HS\(^-\). The rest potential \( E_{316L} \) of stainless steel is gradually shifted to a negative potential. It seems that the products from the LPIG accelerate the anodic reaction of the stainless steel surface. In the presence of OH\(^-\) and HS\(^-\) generated from the LPIG, potentiostatic polarization of the specimen electrode at 0.4 V\( _{\text{SSE}} \) allowed a relatively large anodic current to flow.

Figure 6 is a double logarithmic plot of current density of the stainless steel specimen and time during the potentiostatic polarization when the polarization was started after the LPIG operation for 0, 100, 150 or 600 s, corresponding to the accumulation of 0.0, 1.5, 2.2 or 2.8 \( \times 10^{-3} \) mol dm\(^{-3} \) of HS\(^-\).

After the impedance measurement, EIS was immediately carried out in a frequency range from \( 10^4 \) to \( 10^7 \) Hz at the same potential at 0.4 V\( _{\text{SSE}} \). The specimen in this study has a relatively small area, and the measurements needed to be repeated several times at lower frequencies. A small discrepancy was observed at frequencies lower than 1 Hz, although Kramers–Kronig transformation diagram was satisfied at most frequencies. Figure 8 shows Bode plots of the stainless steel specimen. Although there is some scattering in the data, the plot is fitted with a so-called Randles-type \( R_\text{ct} C R_\text{el} \) equivalent electronic circuit, where \( R_\text{ct} \) and \( R_\text{el} \) are solution resistance and charge transfer resistance, respectively, and \( C \) is capacitance. Since the capacitance of a passive film/electrolyte interface consists of capacitance of the space charge layer \( C_\text{SC} \) and capacitance of the Helmholtz layer \( C_\text{H} \) in series,

\[
\frac{1}{C} = \frac{1}{C_\text{SC}} + \frac{1}{C_\text{H}} \tag{[15]} \]

Assuming that the value of \( C_\text{H} \) is 0.1 mF cm\(^{-2} \) for austenitic stainless steels in alkaline solutions,\(^{18,19} \) the \( C_\text{SC} \) value was close to the measured value of \( C \). Hence, \( C \) is considered to be \( C_\text{SC} \) in this paper. The values of \( R_\text{ct} \), \( R_\text{el} \), and \( C \) as a function of [HS\(^-\)] are shown in Table I. The values of \( R_\text{ct} \) and \( R_\text{el} \) are almost constant because [HS\(^-\)] is less than \( 10^{-6} \) mol dm\(^{-3} \) at maximum and is too low to change the solution conductivity. With increase in [HS\(^-\)] during the passivation, however, \( C \) increases and \( R_\text{el} \) decreases, clearly corresponding to the increase in passivation–maintaining current and the decrease in |Z| shown in Figs. 6 and 7, respectively. It is thought that an electronically damaged passive film was formed by the presence of HS\(^-\).
Figure 9. Mott-Schottky (M-S) plot of the stainless steel specimen after passivation at 0.4 V_{SSE} in a solution containing 0.0, 1.5, 2.2 or 2.8 × 10^{-3} mol dm^{-3} of HS^{-}.

Table I. Values of solution resistance $R_{dl}$, charge transfer resistance $R_{ct}$ and capacitance $C$ from curve fitting with an equivalent electric circuit of $R_{ct}$ in plots when EIS of type 316L stainless steel was performed in a solution containing HS^{-}.

| [HS^{-}] /10^{-3} mol dm^{-3} | $R_{dl}$/Ω cm^{2} | $R_{ct}$/kΩ cm^{2} | $C$/μF cm^{-2} |
|-------------------------------|------------------|-------------------|----------------|
| 0                             | 527 ± 2.03       | 781 ± 20.6        | 15.3 ± 0.11    |
| 1.5                           | 538 ± 1.15       | 741 ± 47.8        | 16.1 ± 0.68    |
| 2.2                           | 527 ± 0.87       | 707 ± 29.7        | 16.5 ± 0.25    |
| 2.8                           | 534 ± 1.52       | 295 ± 6.08        | 17.6 ± 0.23    |

Figure 9 shows an M-S plot of the stainless steel specimen after passivation in the solution with or without HS^{-}. The capacitance was measured at 15 Hz as was the capacitance shown in Figure 7. This frequency is seen in Figure 8 to be in the region dominated by a capacitive response. Though a negative slope is observed at potentials higher than 0.3 V_{SSE}, due to the continuous growth of the film, a semi-conductive property. Regardless of the [HS–] in the solution, a decrease in $N_D$ implies that the presence of HS follows:

The products generated from the LPIG might cause the formation of a more defective film and/or a thinner film partially in the vicinity of the LPIG microelectrode tip. Futhermore, a slightly dark arc is seen on the outside of the brightest circle of the stainless steel specimen. The diameter of the arc is almost the same as the diameter of the glass sheath of the LPIG microelectrode. This region seems to be slightly concentration of dopants is not large enough to affect the structure and chemical composition of the film.

Table II. Values of flatband potential $E_{fb}$ and donor density $N_D$ from M-S plots measured in a solution containing HS^{-}.

| [HS^{-}] /10^{-3} mol dm^{-3} | $E_{fb}$/V_{SSE} | $N_D$/10^{20} cm^{-3} |
|-------------------------------|-----------------|-----------------------|
| 0                             | -0.232 ± 0.004  | 4.19 ± 0.39           |
| 1.5                           | -0.232 ± 0.002  | 4.84 ± 0.59           |
| 2.2                           | -0.234 ± 0.007  | 5.21 ± 0.34           |
| 2.8                           | -0.233 ± 0.002  | 5.99 ± 0.11           |

Figure 10. SECM tip current image of the stainless steel specimen surface, which was polarized at 0.4 V_{SSE} for 100 s in a solution containing 2.8 × 10^{-3} mol dm^{-3} of HS^{-} using Ag/Ag_2S of 500 μm in diameter in the LPIG. Micro-electrode tip and substrate specimen electrode of the SECM were polarized at 0.6 V_{SSE} and −0.2 V_{SSE}, respectively, in deaerated pH 8.4 buffer solution containing 1 × 10^{-3} mol dm^{-3} FcMeOH with an interelectrode distance of 20 μm.
Figure 11. AES depth profiles of the stainless steel specimen after polarization at 0.4 V_{SSE} for 100 s in a solution (a) without or (b) with the LPIG operation containing $2.8 \times 10^{-3}$ mol dm$^{-3}$ of HS$^{-}$.

less reactive than the stainless steel surface distant from the LPIG microelectrode location.

Figure 11 shows an AES depth profile of the stainless steel specimen after polarization at 0.4 V_{SSE} for 100 s in a solution with or without the LPIG operation, in which the estimated [HS$^{-}$] was $2.8 \times 10^{-3}$ mol dm$^{-3}$. It was clear that the specimen surfaces were covered with oxide of the passive film. Assuming that the passive film-substrate interface is located at the transition with a half of the atomic concentration of oxygen, the passive film formed in a solution with HS$^{-}$ shows the same thickness as that of the passive film formed in a solution without HS$^{-}$. It was also observed that a very small amount of elemental S is contained in the outmost passive film of the sample formed in the solution with HS$^{-}$. The atomic concentrations of Fe (Figure 12a) and Cr (Figure 12b) are larger in the passive film formed in a solution with HS$^{-}$ than in the passive film formed in a solution without HS$^{-}$, while the atomic concentrations of Ni (Figure 12c) and O (Figure 12d) in the film with HS$^{-}$ are smaller than those in the passive film without HS$^{-}$, though the difference is relatively small. Metallic Ni seems to be depleted in the film but to have accumulated in the film/substrate interface. These results coincide with results of previous studies.$^{24-27}$

Discussion

The effect of HS$^{-}$ on the passivity of type 316L stainless steel was investigated by using an LPIG microelectrode. Electrochemical and surface analyses revealed that the presence of HS$^{-}$ makes a passive film defective and conductive by increasing oxygen vacancies and metal cations.

It has been widely proposed that the presence of aggressive anions changes the passivity and leads to localized corrosion on stainless steels.$^{28-32}$ Three main depassivation models have been proposed in the presence of aggressive anions.$^{33}$ The adsorption model$^{34,35}$ is associated with the absorption of aggressive anions on the passive film. The adsorbed anions transfer metal cations to the electrolyte by forming a complex of metal cations on the film. As a result, the passive film is thinned and removed. According to the penetration model,$^{36,37}$
the depassivation of metal is due to the transfer of aggressive anions through the passive film to the metal surface. The adsorbed and/or contaminated anions introduce higher ionic conductive paths through the film and lead to a rapid release and removal of metal cations. The passive film breakdown model is related to mechanical breakdown of the film. The adsorption of aggressive anions on the passive film reduces surface tension, resulting in a mechanical break. All of the proposals are based on the prior adsorption of aggressive anions on a passive film followed by the depassivation process of the film. The adsorption of an anion is associated with polarizability when it is adsorbed on metal cations. The higher polarizability the anion has, the stronger is the adsorption of the anion on cations of the passive film. Polarizability of sulfides such as S or HS is approximately two times higher than that of halides and OH. Therefore, the adsorption of HS might be prior to that of OH on a stainless steel surface in a solution containing HS.

When the stainless steel surface was polarized in a solution containing HS, adsorbed HS was preferentially incorporated into the formed passive film. It was confirmed from AES and M-S analyses that elemental S present on the outermost passive film. If the outermost S is present as HS or S2, oxygen anion transfer from the electrolyte to the outermost lattice of the film should be inhibited. In order to maintain a charge balance in the film against the existence of HS or S2, metal cations and/or oxygen vacancies need to be produced at substrate/film and/or passive film/electrolyte interfaces, resulting in the concentrations of metal cations and oxygen vacancies becoming larger in the film. This is also supported by results in Figures 10 and 12 showing that the HS adsorption results in an increase of donor density in the film.

Though it is hardly forming S and S2 from HS in pH 9.5, the polarizability of potential higher than 0.594 VSS enables to induce the oxidation of HS to SO2. Increase in local concentration of HS in the vicinity of the stainless steel specimen surface might lead to a change in the electrochemical potential of the surface. The relatively small impendence of the stainless steel surface formed in the solution with HS was due to the existence of HS in solution during the passive film formation. However, an increase in impedance was also observed during the anodic polarization continuously even after stopping HS enrichment by the LPIG operation. Thus, it is suggested that no oxidation of HS occurs on the stainless steel surface, though further study of the ionic state of S species during a polarization of specimen surface is needed for further understanding about oxidation states of sulfide ions and local acidification of the local solution.

On the other hand, the concentration of Ni decreased in the film when it was formed in the solution containing HS. Olefjord et al. reported that Ni does not participate in passive film formation. Castle et al. suggested that metallic Ni is enriched at the substrate/passive film interface during passivation because it is relatively noble compared with other metallic elements in stainless steel. It is thought that the presence of other enriched metallic elements in a film forming in the solution containing HS makes it difficult for metallic Ni to be concentrated at the interface. In any case, the passivity of the stainless steel surface is strongly affected by the adsorption of HS.

A deteriorating effect of HS on the passivity of stainless steel has been reported. As far as we know, however, this study is the first study to examine the role of HS in the initiation of localized corrosion of type 316L stainless steel using an LPIG. HS adsorption is one of the important conditions causing instability of a passive film, which would be a trigger of localized corrosion of the steel. When the specimen surface in which a defective part had been formed by using the LPIG was polarized in a solution containing a high concentration of CI, we confirmed the formation of pits in the defective part on the surface. It is thought that pitting was preferentially and locally initiated and/or propagated from the defective part of the passive film when the surface was exposed to the CI-containing solution. Passive film degradation of type 316L stainless steel with an LPIG was investigated at higher potentials in various solutions. The critical conditions for degradation and depassivation will be reported in the near future.

Conclusions

The effect of hydrogen sulfide ions (HS) on passivity of type 316L stainless steel was investigated in pH 8.4 buffer solution using the LPIG technique. Galvanostatic polarization of the Ag/AgCl/LPIG microelectrode generated locally both HS and OH on the stainless steel surface. The passivity of the stainless steel became relatively unstable due to the formation of a more defective n-type semiconductor passive film with HS than that formed without HS. AES revealed an increase of metal cations and oxygen vacancies in the passive film formed in a solution containing HS. The adsorption of HS during passivation of the stainless steel surface could lead to the formation of a defective passive film. Change in the stability of a passive film due to the presence of HS would be a trigger for the initial depassivation of stainless steel.

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