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Secondary electron emission of tin and tin-lithium under low energy helium plasma exposure

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A R T I C L E   I N F O

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- Tin-lithium
- Fusion
- Secondary electron emission
- Liquid metals

A B S T R A C T

Secondary electron emission (SEE) yields of tin (Sn) and tin-lithium (SnLi) eutectic (20 at.% Li) samples were measured in He-plasma at a mean incoming electron energy up to 120 eV. SnLi shows a maximum yield of about 1.45 at 110 eV electron energy while the yield of the Sn surface was measured to be maximally 1.05 at 120 eV. X-ray photoelectron spectroscopy (XPS) analysis demonstrated the segregation effect of Li to the surface of the eutectic, both after melting in the argon atmosphere and in molten state with simultaneous He-plasma exposure. At least the top 10 nm of the SnLi samples were heavily enriched with Li, and Sn/Li ratios varied in the range 0.8–5% depending on eutectic treatment conditions. After the plasma exposure Sn3d is detected predominantly in the oxidized state while after extended atmospheric oxidation there was still a significant amount of Sn3d detected in the metallic state. The liquid surface of SnLi indicated a possible decrease of SEE yield. All measurements gave values of SEE yield close to or above unity. Such values can lead to significant plasma sheath disturbances and subsequent additional heat flux from electrons on such a plasma-facing material, thus, should be accounted for in designing fusion reactors using these components.

1. Introduction

Over the last two decades the concept of a liquid metal divertor for a post-ITER nuclear fusion reactor i.e. DEMO has attracted increasing attention [1–3]. Studies suggest liquid metals have favorable properties in terms of power exhaust and self-healing [4–6]. Lithium and tin are considered as two of the most promising candidates due to their physical and chemical properties. For lithium (Li) these include: low-Z value, hence a higher level of impurities can be tolerated before fusion power is significantly degraded; a low melting point; and improved discharge stability in tokamaks [7–9]. As for tin (Sn), it has a wide operational window due to its low melting and high boiling point in combination with a relatively low evaporation rate and could potentially exhaust power densities up to 20–25 MW/m\textsuperscript{2} [5,10]. The idea to use the advantages of both metals in the eutectic of SnLi has been proposed in several papers such as [11–13], but the properties of such the eutectic when exposed to a plasma are not well studied. Thus, the characterization of the eutectic in comparison to its constituent elements is still necessary.

An important property of a plasma facing material (PFM) is the rate of emission of secondary electrons relative to the incoming particle fluxes. The secondary electron emission (SEE) yield represents the outgoing amount of electrons per each incident electron as a function of the energy of the incoming particle. Generally, at energies below several hundred eV only the emission stimulated by electrons is important [15] and therefore we restrict our discussion and study here to the electron stimulated emission. SEE can lead to a modification of the sheath which consequently will increase the floating potential and provide an additional heat from increased electron flux [14,15]. The magnitude of the extra heat arriving at the surface originating from high SEE can be several times larger than the heat flux on a material with no or marginal SEE yield (Y_{\text{see}}) [14]. Therefore, the power exhaust capability of a metal surface can be limited by this process.

The influence of SEE on plasma sheath and the corresponding rise of the heat flux was estimated in several works such as [14–17]. The classical sheath model can still describe marginal SEE [15,18,19], but even in this case when Y_{\text{see}} approaches unity the SEE impact on the sheath layer is significant, as can be seen through Eqs. 1 and 2 which represent the floating potential (V_f) and the electron heat flux (q_{e,\text{surf}}) to the surface respectively [15]:

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\[ V_f = \frac{kT_i \text{ln} \left( \frac{1 + \frac{e}{Y_e}}{1 - Y_e} \right)}{2e} \] (1)

\[ q_{i, \text{surf}} = \frac{2kT_i j^i}{(1 - Y_{i,\text{sec}})^{e/2}} \] (2)

where \( k \) is the Boltzmann constant, \( m_o, m_i \) are respectively the masses of electrons and ions, \( T_e, T_i \) are respectively the electron and ion temperatures, \( Y_{i,\text{sec}} \) is the secondary electron yield and \( j^i \) is the electron current density striking the surface.

As can be seen both equations approach infinity as \( Y_{i,\text{sec}} \) approaches unity and the sheath model is therefore insufficient. A modified sheath to account for this can be described with a space-charge-limited (SCL) model, where a virtual cathode appears in the sheath, limiting the electron losses from the surface [20–23]. Furthermore, when the yield is even larger some models predict a reverse sheath (RS) [24–27]. The SCL model suggests an increased heat flux and a corrected floating potential, but the RS model implies that the sheath can be reversed or even disappear [26]. This will lead to extremely high heat load because electrons will not be decelerated at all in the sheath (as considered in the classical model) and thus an increased flux of power and electrons will be deposited on the PFM. This can therefore substantially limit the power exhaust capability of such a material.

In this paper we measure the \( Y_{i,\text{sec}} \) of Sn and SnLi under low energy He-plasma exposure, as they are considered to be prospective candidates for a liquid divertor concept. In particular, the \( Y_{i,\text{sec}} \) of SnLi has not previously been measured, while this represents the first time this measurement methodology is used for the \( Y_{i,\text{sec}} \) of Sn. The segregation of Li to the surface of the eutectic mixture is also studied before and after etching in the concentrated hydrochloric acid. The experimental apparatus and arrangements are described in Section 2.1. The sample design and the preparation process is given in Section 2.2, while Section 2.3 outlines the experimental procedure and results. Finally, the discussion of the obtained measurements and conclusions are given in Sections 3 and 4, respectively.

2. Experimental apparatus and procedures

2.1. Setup

A detailed description of the experimental setup is given in [28,29]. In this section we briefly outline the main elements and specify the important modifications that were made. The vacuum chamber consists of an anode; a port for a sample holder with a built-in heater and a thermocouple; and another port for a disk probe with a grid [30] (figure 1). A glow discharge is created in a helium gas between the walls, which are grounded and act as the cathode, and the anode. Each sample was exposed to glow discharges at a variety of gas pressures. This variation was used to make a valid determination of the electron energy distribution and accurately determine error bars. The following discharge parameters were varied depending on the experimental series, with higher voltages and currents used at higher gas pressures: the discharge voltage (220–400 V), the current (275–525 mA) and the gas pressure (1.6 × 10^{-3} to 8 × 10^{-5} mbar). In this range of parameters, we previously measured electron densities of 4 × 10^{14} m^{-3}–1.03 × 10^{15} m^{-3} and electron temperatures of 6.5–10.4 eV [29]. The background pressure was 2 × 10^{-6} mbar and the heater temperature was varied in the range 295–623 K dependent on the choice of the solid or the liquid surface to be measured.

2.2. Sample preparation and characterization

Samples were made of tin or tin–lithium eutectic (nominally lithium 20 at. %, Princeton Scientific Corp.). Round stainless steel (SS304) disks of 20 mm were used as a substrate. The substrate surface was mechanically polished to ~100 μm roughness and chemically treated with concentrated hydrochloric acid (37%) to provide a good adhesion of the molten metal to the substrate (Fig. 2). The Sn and SnLi were melted in a separate vacuum chamber with a residual gas pressure of about 6 × 10^{-7} mbar. The substrate surfaces were then coated with the molten metal and subsequently cooled to the room temperature in vacuum prior the transfer to the exposure chamber. The coating thickness was measured to be 5 mm.

It was previously observed that the SnLi composition evolves under melting, leading to the enrichment of the surface with Li relative to the stoichiometric ratio [12]. To attempt to understand the actual surface which produces the SEE, SnLi samples were analyzed using X-Ray Photoelectron Spectroscopy (XPS). The experimental apparatus and arrangements are described in Section 2.1. The sample design and the preparation process is given in Section 2.2, while Section 2.3 outlines the experimental procedure and results. Finally, the discussion of the obtained measurements and conclusions are given in Sections 3 and 4, respectively.

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The first state was as received from the manufacturer and analyzed with XPS (made from type 1, notation “as received” in Fig. 3). This sample had predominantly been stored in a sealed air-tight container prior to measurement.

The second state was after melting in argon atmosphere, subsequent solidifying, but no plasma exposure (made from type 1, notation “Ar melt” in Fig. 3). Its only atmospheric exposure was during transfer to the XPS machine. The purpose of melting in argon ( inert...
The Li₁s in the Ar melted sample is significantly higher (+1 eV) than the other two and is likely due to the presence of different compounds compared to the others (see the discussion section). XPS shows the other components present to be Sn, carbon and oxygen groups. The third state was melted with the heater in the plasma chamber and afterwards exposed to the He-plasma used in these experiments (made from type 2, notation “He exposed” in Fig. 3). Following this exposure, it was stored for several days in atmosphere prior to XPS testing.

The XPS measurement of the “as received” sample (green line in Fig. 3) demonstrates two chemical states of Sn: the peaks at 485 eV and 493 eV correspond to the metallic state whereas the peaks at 487 eV and 495 eV correspond to the oxidized state of the Sn₃d peak [31,32]. The results from the “Ar melt” sample (red line in Fig. 3) shows that Sn is present mainly in the metallic state and only a marginal fraction is in the oxidized state. This implies that the surface oxide layer can be removed by the melting process, presumably subsumed within the liquid, and replaced by the metallic Sn at the surface. The Sn₃d peak of the “He exposed” sample (blue curve in Fig. 3), shows Sn only in the oxidized state [31,32] (peaks are shifted to ∼487 eV and further). This is clearly different from the “as received” sample that was also stored for prolonged time at atmosphere and may relate to the more moist atmosphere it was exposed to compared to the storage box used predominantly for the as-received sample.

Analysis of the Li₁s peak of the SnLi eutectic shows that Li is always present in a compound state (Fig. 3). This is due to its high reactivity with, for example, the oxygen, nitrogen and water vapor from the atmosphere [37,38]. Also based on the total XPS spectra the formation of more complex molecules containing hydrogen and COₓ groups are suspected [38]. The Li₁s peak for the “as received” and “He-exposed” sample are similar, probably due to the prolonged exposure to atmosphere in both cases and are shifted slightly to higher binding energy compared to lithium in the metallic state (Fig. 3). The binding energy of the Li₁s in the Ar melted sample is significantly higher (+1 eV) than the other two and is likely due to the presence of different compounds compared to the two others (see the discussion section). XPS shows the other components present to be Sn, carbon and oxygen groups.

If we now compare XPS measurements from both peak types (Sn and Li) we can conclude that:

- In the “as received” sample Sn and Li both are present in compound (oxygen-containing) states. However, there is also a metallic state Sn (green curves in Fig. 3).
- For the “Ar melt” sample different lithium compounds are dominant, while Sn is predominantly in the metallic state (red curves in Fig. 3).
- XPS measurements from the “He-exposed” sample show a Li peak at the same position as the “as received” sample in the compound state and Sn peak only in the oxidized state (blue curves in Fig. 3).

All eutectics show similar XPS results in terms of large amounts of lithium presence at the surface. Sn to Li ratios vary from 0.8% to 5%, as is shown in Table 1. These measurements are consistent with the segregation effect previously found for an eutectic SnLi sample similar to our type 1 which appears after melting [12]. It is important to mention that the XPS probes only the top surface. As lithium is the majority constituent of the XPS measurement in a compound state, intensity can be measured up to 10 nm below the surface in all samples. On the other hand, this is the same region where secondary electrons are generated. We also observe that after melting the sample surface is increasingly enriched with lithium, both for the melt in Ar as for the He exposed sample. From this one can expect that the plasma-surface interaction in the melted state should be dominated by lithium interaction with charged particles and not tin, despite the lithium concentration of the compound being only 20 at.%. 

### 2.3. SEE measurements and results

Sn and SnLi samples were exposed in a helium plasma, preceded by an argon sputtering discharge. The argon sputtering was carried out to remove oxides which can form during sample installation in atmosphere and can influence the SEE yield [33]. It should be noted however that the oxidation (from background pressure) of the surface during measurements affects the magnitude of the SEE yield, but this is consistent with the expectations of real vacuum conditions. The vacuum conditions of a divertor region of a fusion device will not have an ultra-high vacuum: a working neutral pressure of 1–10 Pa is predicted during operation with a background pressure of 10⁻⁴ – 10⁻⁶ Pa [34,39]. Therefore, a partial contamination with oxygen of the metal surface will be present.

We replicated experimental conditions and procedures reported in our previous studies [28,29] in terms of gas pressures, discharge currents and voltages (their range is listed in the Section 2.1). Furthermore, we aimed to research SEE not only of the solid state metals but also of molten samples. The measurements consisted of sample current

### Table 1
Relative composition of the SnLi eutectic according to XPS atomic concentrations.

<table>
<thead>
<tr>
<th></th>
<th>as received</th>
<th>Ar melt</th>
<th>He exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn/Li</td>
<td>0.052</td>
<td>0.017</td>
<td>0.008</td>
</tr>
</tbody>
</table>
measurements (obtaining I-V curve of a sample), then probe measurements of the current (I-V curve of a disk-probe). Afterwards based on the measured sample currents we calculated $Y_{\text{see}}$ and based on the disk-probe I-V curves we calculated mean energy of incoming electrons. Briefly, the present experimental series can be described as following:

1. A current-voltage (I-V) characteristic was measured by sweeping an applied bias on the sample (Fig. 4a), thus attracting a changing ratio of electron to ion currents from the plasma to the sample surface. The linear part of the negative I-V characteristic (Fig. 4b) contains the ion saturation current which is subtracted from the total current drawn by the sample. After the subtraction the I-V curve consists of the sum of the incident electron current ($I_{\text{inc}}$) and the secondary electron emission current ($I_{\text{SEE}}$) represented in Fig. 4c.

2. To obtain $I_{\text{inc}}$ an I-V characteristic was measured using the gridded disk probe [30]. The bias of the collector was fixed at the maximum voltage of the sample in the previous step, plus an extra 50 V to compensate for the potential drop in the plasma sheath [29]. The voltage on the grid was varied over the same range as on the sample in step 1. Only $I_{\text{SEE}}$ is therefore measured on the collector because all secondary electrons return to the collector surface due to the high applied bias. In the calculation of $I_{\text{inc}}$ two geometrical factors were applied to compare with the current measured on the sample: the first to account for an area difference between the collector and the sample; the second to account for the shadowing effect of the grid, which can block electrons from reaching the collector surface.

3. The SEE yield was calculated as the ratio between $I_{\text{SEE}}$ and $I_{\text{inc}}$ as a function of voltage bias:

$$Y_{\text{SEE}}(V_{\text{bias}}) = \frac{I_{\text{SEE}}(V)}{I_{\text{inc}}(V)}$$

4. To characterize the SEE yield as a function of the mean electron energy an electron energy distribution function (EEDF) was calculated using the disk probe measurements. This was made by finding the derivative of the current on the probe:

$$f(-qV) = \frac{m}{q^2A} \frac{dI}{dV}$$

where $f$ is the electron energy distribution function, $q$ is the elementary charge, $m$ is the mass of electron, $A$ is the area of the probe, $I$ is the current on the probe and $V$ is the voltage on the probe. From this the mean electron energy can be calculated as a function of the bias voltage fitting it with a bi-Maxwellian distribution using MATLAB as:

$$E_{\text{mean}}(V_{\text{bias}}) = \frac{\int_{qV_{\text{bias}}}^{\infty} (E - q(V_{\text{bias}} - V_{\text{bias}})) f(E) dE}{\int_{qV_{\text{bias}}}^{\infty} f(E) dE}$$

5. Finally, we can combine the two functions $Y_{\text{SEE}}(V_{\text{bias}})$ from Eq. 3 and $E_{\text{mean}}(V_{\text{bias}})$ from Eq. 5 into a dependence of the SEE yield on the mean electron energy i.e. $Y_{\text{SEE}} = Y_{\text{SEE}}(E_{\text{mean}})$.

Fig. 5 represents the dependence of the $Y_{\text{SEE}}$ on $E_{\text{mean}}$ of Sn and SnLi eutectic. The data points to obtain $Y(V_{\text{bias}})$ and $E_{\text{mean}}(V_{\text{bias}})$ were accumulated during six measurement series (three per element) at different gas pressures and discharge voltages. This procedure was made...
to verify the EEDF in different conditions and to accumulate enough data to account for statistical effects. It is worth to mention that SEE yield calculated for small energies (in the range below 50 eV) should be interpreted with a great care. At such small incident electrons energies, the secondary electrons are hardly distinguishable from the incoming electrons [35]. The currents at lower electron energies are rather small and thus there are bigger fluctuations in the measurements. This uncertainty is reflected in the larger error bars as the electron energy decreases towards zero.

The next measurement series were devoted to molten samples and XPS analyses were carried out afterwards (see previous section eutectic type 2). SnLi samples were melted at $T = 613–623$ K using the heater. A small overheating above melting point [36] followed by extended heating for 30 min were made to ensure a complete melting of the sample volume. Measurements of the sample and probe currents in a liquid state i.e. after melting however gave unexpected I-V curves (Figs. 6 and 7).

At low gas pressure the molten SnLi sample I-V characteristic has only the linear part over nearly the entire biasing range (blue dotted line in Fig. 6). Moreover, the electron current measured on the disk probe does not change much and even does not have a steep rise as can be expected (blue dotted line in Fig. 7). This indicates that the population of super-thermal electrons was not affected, but the population of cold electrons was dramatically decreased. With the increase in gas pressure a drastic change is observed (compare blue to the black lines in Figs. 6 and 7). Both sample and probe characteristics become similar to the I-V characteristics of the solid sample (see Fig. 4 and red dashed line in Figs. 6 and 7). The increased helium pressure leads to an increase of charged particle density as the power supplied to the plasma discharge was increased with the increased gas pressured. On the other hand, the flux of evaporated tin and lithium is defined by the sample temperature and therefore remained the same in both experiments. Thus the pressure dependence observed here indicates that the melting and strong metal evaporation had a large influence on the measured currents. The causes of this are discussed in the next section. Unfortunately, it also suggests that the method used to measure SEE yield of solid samples may be limited for measuring the liquid surface $Y_{\text{see}}$. However, using the higher pressure values, a yield of liquid SnLi was measured (Fig. 5), but due to the complications described above statistical accumulation and a reliable error estimation was not possible and the results should be treated with caution.

3. Discussion

The XPS results clearly show that both Sn and Li can be strongly affected by atmospheric exposure. For Sn it is well known that it will slowly oxidize to SnO2 which is consistent with the observations of the “as-received” and “He exposed” samples. The lack of metallic tin in the latter case likely indicates that it is fully oxidized within the first 10 nm, while this is not completely true for the “as-received” sample and therefore a mixture of states is observed. Melting in an inert atmosphere permits metallic tin to be dominantly at the surface relative to the thin tin-oxide layer which is presumed to be subsumed into the melt. For Li the reactions are more complex. In the moist atmosphere lithium rapidly forms lithium oxide and nitride (LiO2 and Li3N), but within a few hours it is predominantly converted to LiOH in the presence of water vapor [37]. On longer timescales it forms lithium hydroxide monohydrate (LiOH·H2O) and lithium carbonate (Li2CO3) in the presence of water vapor and carbon dioxide respectively [37,38]. Likely this gives rise to the differences in XPS signal for the “Ar melt” sample which had only a short atmospheric exposure compared to the other two.

The implication for the measurements in terms of impurities at the surface is quite limited however as all samples were sputtered with argon prior to the experiments. It is expected that this would efficiently remove all compounds from the surface. For Sn the oxidation is likely negligible during the experiment, which is supported by the XPS results. For Li the top monolayer will oxidize after exposure to 1–2 l of oxygen which would be expected within 1–10 s at our background pressure [39]. However, the He plasma exposure with swept biasing may be expected to also remove the oxygen again, therefore we would suppose some oxygen (and nitrogen) presence on the SnLi surface but not full coverage. What is more significant is that it can be expected that for the SnLi samples the surface is dominated by Li, despite making up only 20 at.%

The dependence of $Y_{\text{see}}$ on $E_{\text{mean}}$ revealed clear differences between the yield of Sn, SnLi and Li (Fig. 5). The maximum value of the $Y_{\text{see}}$ of the solid SnLi is almost 50% bigger than the yield of solid tin, and about three times higher than the solid lithium surface when the electron mean energy is $\sim$90 eV ($Y_{\text{see}} \sim 0.5$), as measured in [40,41]. However, in the work [42] the Li SEE yield was measured to be about 2.2, i.e. around 4 times higher than in [40] and larger than that for SnLi reported here. Such a difference may be attributed to the effect of different experimental conditions as in [42], as surface contamination by oxygen was much higher. SnLi $Y_{\text{see}}$ is about 1.4 times smaller than a lithium surface contaminated with oxides and nitrides, as studied in [40,41]. This may indicate that oxide and nitride contamination is less extensive in the SnLi measured here. XPS spectra also show that the “He-exposed” sample does not have the Sn3d metallic peak unlike others. One contributing factor could be due to the increased ratio of
Li/Sn on the surface (see Table 1) which leads to a thicker Li-oxide layer, while the probing depth of XPS remains unchanged. Therefore, the metallic Sn is completely obscured at the surface and only the oxidized Sn is present.

The observed currents measured at the low pressure during the molten SnLi experiments had two issues. Firstly, only a small cold electron population was observed which made determination of the EEDF impossible; and secondly the ion saturation currents measured on the sample were much larger than in all other cases. At higher gas pressures and therefore higher plasma densities these problems disappeared. Therefore, we propose that the Li evaporation can explain both observations.

If one assumes a segregation effect of lithium reported in [12], then the surface of the sample should be enriched with Li atoms. Furthermore, our XPS measurements made after exposures are consistent with [12] and also show the surface enrichment with Li. It should be noted that XPS attenuation length is bigger comparing to the low-energy ion scattering (LEIS), a technique used in [12]. We estimated the attenuation length of 6 nm for Li and 4 nm for LiO2 based on the XPS sensitivity data reported in [43]. These atoms can be evaporated and the evaporated flux of lithium atoms therefore cools down the plasma. Assuming the evaporation is predominantly as a pure lithium surface the evaporation rate of Li atoms can be estimated from [44] to be $1.1 \times 10^{20} \text{m}^{-2} \text{s}^{-1}$ at 623 K. At low gas pressures this is comparable to the incoming plasma flux and may be expected to have a significant effect on the plasma, for example by cooling the cold electron population and affecting the plasma potential so that they are not recorded. At higher pressures the problem is less extensive indicating that the denser plasma is less strongly affected as the evaporated particles make up a relatively smaller ratio to the incoming plasma flux.

Another effect of the intensive lithium evaporation is its deposition on the near sample parts of the setup. The big increase of the sample current (blue dotted line in Fig. 6) can be attributed to the enlarged effective area of the sample. The continuous evaporation of lithium and its subsequent deposition on the sample insulation lead to larger conducting and hence biased area. Therefore, the current measured on the sample is increased. I-V characteristics shown in Fig. 6 were measured in several experiments after each other, with the lowest pressure experiments carried out much later than the others. This complication prevented us from gathering enough statistics for molten SnLi SEE yield. Nevertheless, when the deposited amount of lithium is negligible, the technique can still be used to measure the SEE yield. This was demonstrated in experiments with clean insulation parts in the beginning of the experimental series with the molten SnLi (black solid line in Figs. 6 and 7). In these experiments while the deposition is negligible and the biased area is fixed to the sample dimensions, the increase of helium pressure with adjusted power supplied to the discharge resulted in the higher electron current on the probe. This occurs due to the rise in density of sufficiently energetic charged particles in the discharge. As a result, we can observe that the molten sample and probe I-V curves become similar to I-V curves of a solid SnLi sample. We managed to extract a yield measurement for a liquid SnLi as well (Fig. 5). But the values should be treated with a great care due to above discussed evaporation and electron cooling effects.

4. Conclusion

Investigation of the SEE of Sn and SnLi under helium plasma has been performed. Our measurements show that eutectics of only 20% atomic lithium in the tin bulk increases $Y_{\text{see}}$ almost 1.5 times comparing to the pure tin at electron energies of 110 eV. It also is 3 times higher than pure lithium surfaces ($Y_{\text{see}} \approx 0.5$), but about 60% lower than a lithium surface with heavy nitride and oxide contamination [40]. Molten SnLi demonstrates a lower yield compared to solid state which may indicate a reduction in oxides and nitrides at the surface. XPS analysis shows the segregation of Li to the surface of the SnLi eutectic after melting and after He-plasma exposure. This is consistent with previously reported observations [12]. Sn was measured to be in an oxidized state both in as received and after plasma exposure, while after fresh melting in Ar atmosphere it is observed mostly in the metallic state. Li is present in the LiI compounds state but on short timescales the compounds are different compared to on longer timescales. The relative ratio of Sn/Li varied from 0.8 – 5% at the surface (depth of about 10 nm in all samples).

Molten surfaces of Sn and SnLi demonstrate certain complications in the technique used for measurements of $Y_{\text{see}}$ of solid metals. Despite this however the SEE for SnLi could be measured using higher He gas pressure. The liquid surface of SnLi shows a significant drop of SEE comparing to its solid state. This might occur due to the high evaporation of Li from the surface and the subsequent drop in the electron energy density function, or from the reduction in impurities at the SnLi surface relative to the solid SnLi.

In all cases, except for the solid Sn, a SEE yield very close to or greater than one was observed. SEE yield above unity may lead to overheating of the surface. Therefore, the power load on the SnLi eutectic can be limited by the sheath disturbance and the increased heat flux from electrons. On the other hand, a liquid surface of the SnLi indicates a partial suppression of this effect when the incoming electron mean energy is greater than $\sim 60$ eV. As for tin in the solid state it demonstrates a yield below unity when the incoming electron mean energy is lower than $\sim 80$ eV, which is consistent with [33].

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