In Lu et al.’s comment, the possibility of achieving textured crystal growth on textureless polycrystalline substrates is questioned. As stated in Lu et al.’s comment, their doubt arises mainly from two claims: (1) the unlikelihood of growing a textured film on textureless substrates, e.g., “It is hard to imagine that the Li electrodeposits of dominant 110 texture could be grown on polycrystalline Cu foil,” and (2) methodological errors associated with use of θ–2θ scan to identify material textures, e.g., “The crystallographic texture (preferred orientation) was determined by θ–2θ scan x-ray diffraction (XRD).” Unfortunately, both claims reflect misunderstanding of the complexities of crystal growth associated with electrodeposition reactions in an electrochemical cell.

We first address the question about the possibility of growing textured films on textureless substrates. There is in fact a large body of readily available literature (an abbreviated list is provided in Table 1), which reveals textured electrodeposition on textureless substrates1–4. A better question then might be the reverse of the question posed by Lu et al.: why are many electrodeposited metal films textured, even when deposition occurs on textureless substrates? The answer to this latter question requires precise understanding of how crystalline metals nucleate and grow at interfaces in an electrochemical cell. Crystal growth of metal deposits in electrochemical cells typically occurs at a planar/nearly-planar electronically conducting substrate in a multi-step sequence: transport of solvated metal ions to the interface; desolvation of the ions; and electroreduction to form the metal deposit. Importantly, each of these processes occur in anisotropic chemical potential, electric, and stress (via the polymeric separator) fields in the electrochemical cell. It is now well received knowledge that growing crystals in anisotropic fields drives electrochemical crystal growth in preferred orientations, in the absence of any texturing of the electric, stress, chemical potential, etc., drives electrochemical crystal growth in preferred orientations, in the absence of any texturing of the substrate (see Table 1). Some of these studies in fact show that the growth in preferred orientations, in the absence of any texturing of the electric, stress, chemical potential, etc., drives electrochemical crystal growth in preferred orientations, in the absence of any texturing of the substrate. Impor-

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| Year | Methods          | Material         | Substrate | Harris's method /Lotgering factor | DOI                      |
|------|------------------|------------------|-----------|----------------------------------|--------------------------|
| 1987 | Electrodeposition | Nb               | Cu        | Yes                              | 10.1007/BF01023291       |
| 2000 | Electrodeposition | Ni               | Cu        | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2000 | Electrodeposition | Ni               | Brass     | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2001 | Electrodeposition | Zn               | Steel     | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2005 | Electrodeposition | TiB₂              | Graphite  | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2005 | Electrodeposition | Fe-Ni alloy      | Steel     | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2005 | Electrodeposition | In doped ZnO     | Cu        | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2006 | Electrodeposition | Zn               | Steel     | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2007 | Electrodeposition | Au and Cu wires  | Cu        | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2007 | Electrodeposition | Ni-based composites | Steel | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2007 | Electrodeposition | Zn-Co alloy      | Steel     | Yes                              | 10.1016/j.surfcoat.2000.11.035 |
| 2011 | Electrodeposition | Cu               | Ni-P alloy| Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Electrodeposition | Fe doped CdSe    | ITO       | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Electrodeposition | ZnO              | FTO       | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Electrodeposition | Zn               | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Electrodeposition | Ni-based composites | Steel | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Electrodeposition | Cu               | SiO₂ coated Si | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Electrodeposition | Zn               | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2012 | Electrodeposition | AI               | W-Cu alloy| Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2013 | Electrodeposition | CdSe             | ITO       | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2013 | Electrodeposition | Zn               | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2013 | Electrodeposition | Ni               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2014 | Electrodeposition | Ni-TeO₂           | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2014 | Electrodeposition | Ni-Al             | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2014 | Electrodeposition | Cu               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2015 | Electrodeposition | W                | Mo        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2015 | Electrodeposition | Ni               | Pd coated Cu | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2017 | Electrodeposition | In               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2017 | Electrodeposition | Zn               | Glassy carbon | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2018 | Electrodeposition | Au and Cu wires  | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2019 | Electrodeposition | Co               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2019 | Electrodeposition | Cu doped SnS     | ITO       | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2020 | Electrodeposition | Zn-Co alloy      | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2020 | Electrodeposition | Zn               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2020 | Electrodeposition | Co               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2021 | Electrodeposition | Sn               | Ni        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2021 | Electrodeposition | Bi               | Cu        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1975 | Vapor deposition  | TiN              | Fe        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2003 | Vapor deposition  | TiC/TiB₂         | WC        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1988 | Vapor deposition  | PbTiO₂           | Ti        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1991 | Vapor deposition  | Diamond          | Si        | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1992 | Vapor deposition  | Al doped ZnO     | Glass     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1995 | Vapor deposition  | SiC              | Graphite  | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1995 | Vapor deposition  | CdTe             | ITO       | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1996 | Vapor deposition  | CrN              | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 1997 | Vapor deposition  | RuO₂             | SiO₂ coated Si | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2009 | Vapor deposition  | TiO₂             | Quartz and Si | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2009 | Vapor deposition  | TaC              | Graphite 002 | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Vapor deposition  | Ga doped ZnO     | Glass     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2011 | Vapor deposition  | TaC              | Graphite 002 | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2012 | Vapor deposition  | SiC              | C         | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2014 | Vapor deposition  | ZnO              | Glass     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2016 | Vapor deposition  | AuN              | Steel     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2019 | Vapor deposition  | TiN              | Steel, WC, etc. | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2020 | Vapor deposition  | Ga doped ZnO     | SiO₂ coated glass | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2020 | Vapor deposition  | Ir₂O₃            | Glass     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
| 2021 | Vapor deposition  | Diamond          | WC-Co     | Yes                              | 10.1016/j.surfcoat.2011.02.011 |
have in fact been consistently used in the field of electrodeposition/electrometallurgy\textsuperscript{19,23}, as well as in other fields\textsuperscript{24,25}, to characterize textures. An abbreviated list of these studies is provided in Table 1.

So why are the \(\theta-2\theta\) scans so useful? To the first order approximation, the integrated X-ray diffraction intensity of a given peak of a textureless material (e.g., powder) in a \(\theta-2\theta\) scan can be calculated as

\[
I_{hkl} \propto |S_{h0l}|^2 M_{h0l} L_p(\theta) e^{-\beta^{m0l}},
\]

where \(S\) is the structure factor, \(M\) is the multiplicity, \(L_p(\theta)\) is the Lorentz-polarization factor and \(e^{-\beta^{m0l}}\) is a temperature-dependent factor. In a \(\theta-2\theta\) scan, however, only crystals with (hkl) planes aligned roughly parallel to the surface will satisfy the kinematic diffraction condition and contribute to the experimentally measured pattern (see Fig. 1). For a given crystal structure, the only possibility for the relative peak intensity ratio in a \(\theta-2\theta\) scan to deviate markedly from this result (e.g., intensification and absence of certain peaks) is to form textures\textsuperscript{23}. For example, in the extreme case of single crystal or singly-oriented crystallites with (hkl) parallel to the film surface, only the (hkl)-family reflections can be detected. By comparing the measured diffraction pattern to the textureless powder's pattern (i.e., calculating the texture coefficient

\[
P_{h0l} = \frac{I_{h0l}}{\sum_{hlm} I_{h0l}} / \frac{I_{h0l}}{\sum_{hlm} I_{h0l}}
\]

one is able to assess if the material is textured, and if so, which planes are preferentially aligned with the film surface and to what extent\textsuperscript{24}.

A perhaps obvious caveat is that this analysis assumes the texture does not possess a significant off-ND component; \(\theta-2\theta\) obviously cannot capture texture with complex off-ND components since it only measures diffraction from the crystallites parallel to the film surface. For example, \(\theta-2\theta\) cannot capture the orientational order of a zero-background plate made of intentionally miscut quartz or Si single crystal\textsuperscript{20,21}. This possibility, however, is clearly ruled out by the 2D diffraction pattern in Fig. 2a of our original paper, which Lu et al. do not appear to notice. Therefore, the strong intensification of the \(110_\text{Li}\) peaks and the significant weakening/absence of other Li peaks in the XRD patterns shown in Fig. S3 of the original paper—which were collected using a point detector in symmetric \(\theta-2\theta\) scans—reflect the existence of a significant preferred orientation in the electrodeposited Li films.

Instead, Lu et al. attribute the absence of \((200)_\text{Li}\) to the change of irradiated volume as the incident angle increases, and cited Tie et al.’s data on \(\text{Zn}_4\text{SO}_4(\text{OH})_6\cdot5\text{H}_2\text{O}\) for support. We were initially intrigued by this point and studied the \(\text{Zn}_4\text{SO}_4(\text{OH})_6\cdot5\text{H}_2\text{O}\) results. According to Lu et al.’s argument on the decreasing irradiated volumes at higher incident angles, the diffraction intensity should exhibit a downward shift; that is, the intensity ratio between \(002\) and \(003\) should be greater than 100:77 measured in a textureless powder sample. The experimental results presented by Tie et al. can be straightforwardly shown to directly contradict the very claim made by Lu et al.: the \((003)\) peak intensity is in fact even higher than the \((002)\) peak intensity (e.g., see Fig. S11 in Tie et al.’s paper\textsuperscript{22}). The authors also regrettably do not appear to notice that the electrodeposited Li in our work is thicker than 50 microns. The change in irradiated volume may introduce a slopy background or a small deviation from the theoretical intensity ratio to the diffraction pattern, but can by no means suppress the emergence of a major peak, e.g., \((200)_\text{Li}\), in Fig. S3 in our paper. More importantly, the incident beam is fixed at a constant angle when collecting each 2D XRD pattern, resulting in a constant irradiated volume. This simple fact evidently invalidates Lu et al.’s statements that attribute the weakening of \((200)_\text{Li}\), in 2D XRD patterns to the changes in the irradiated volume.

In somewhat more rigorous terms, one might contend that the sample could have out-of-plane fiber textures of more than one Li planes—e.g., \((110)_\text{Li}\) and \((200)_\text{Li}\)—at the same time from different crystallites. Fixing the incident X-ray at the Bragg angle of \((110)_\text{Li}\), diffraction from other planes, e.g., \((200)_\text{Li}\), will not be triggered since the Laue condition is not satisfied for those otherwise fiber-textured crystallites. The \(\theta-2\theta\) scans shown in Fig. S3, however, evidently do not support this conjecture because the existence of the additional fiber textures would produce pronounced diffraction with the symmetric setup used for the experiments. Specifically, in this set-up the incident angle is varied within a large range capturing the Bragg angles of the major peaks of Li. We’ve therefore invalidated all possibilities, but that the Li films in question have \((110)\) out-of-plane preferred orientation.

We note further that Lu et al.’s comment that the \((211)_\text{Li}\) ring is beyond the 2D detector’s measurement range is also incorrect. The range of interest selected for the 2D XRD characterization is from \(-33.4^\circ\) to \(-66.2^\circ\), which covers all the major peaks of lithium and copper, including \((110)_\text{Li}\) at \(-36.3^\circ\), \((111)_\text{Cu}\) at \(-43.4^\circ\), \((200)_\text{Cu}\) at \(-50.8^\circ\), \((200)_\text{Li}\) at \(-52.3^\circ\), \((211)_\text{Li}\) at \(-65.1^\circ\). In Fig. 2D of the original paper, the readers can clearly see the strong \((111)_\text{Li}\) peak of \((200)_\text{Cu}\), \((110)_\text{Li}\) peak of Li, and very weak diffraction of \((200)_\text{Cu}\) and \((211)_\text{Li}\). The color-contour scale is fair for all the samples.

Finally, we address a number of perhaps minor, but again problematic statements made by Lu et al. The authors state, for example, that texture is the “professional term” but preferred orientation, crystal orientation, etc. are not. This view is in fact quite incorrect and contradicted by the literature\textsuperscript{23,24}. Additionally, Lu et al. analyze the 2D patterns and conclude Li is textureless based on the absence of “strong spots” within a small \(\chi\) angle of the Debye-Scherrer rings limited by the area of the detector. Strong spots are generated by single crystals or singly-oriented crystallites; significant mosaicity can obviously exist for textured materials\textsuperscript{25}. Lu et al. also referenced our recent work on deformation-induced textures and invoked similar arguments against the texture identification\textsuperscript{21}. Interestingly, Fig. 1 of ref. 24 demonstrates a good consistency between X-ray diffraction and atomic-resolution transmission electron microscopy (TEM), which again directly challenges Lu et al.’s assertions. Beyond the phenomenology, it is as important to point out that these observations are consistent with theories on the mechanisms of metal deformation. Indeed, as authors of ref. 25, we concur with Lu et al. that TEM—particularly under cryogenic conditions—is becoming a powerful tool to characterize the spatial, chemical and crystallographic information of metal anodes\textsuperscript{26}. Unfortunately, a careful reading of that paper would again show (quite unsurprisingly) that Li tends to expose \((110)\) plane and develop \((110)\) texture upon deposition\textsuperscript{27}. To conclude, we point out to the readers that a broader context and library of relevant resources about texturing of battery electrodes, as well as about nuances associated with texture characterization, is available in a recent review\textsuperscript{28}.

**Data availability**

No new data were generated for the reply.
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Author contributions

Q.Z., J.Z., and L.A.A. wrote and revised the paper.

Competing interests

The authors declare no competing interests.

Additional information

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