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Hybrid reflections from multiple x-ray scattering in epitaxial bismuth telluride topological insulator films

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ABSTRACT

Epitaxial films of bismuth telluride topological insulators have received increasing attention due to their potential applications in spintronic and quantum computation. One of the most important properties of epitaxial films is the presence of interface defects due to the lateral lattice mismatch since electrically active defects can drastically compromise device performance. By describing hybrid reflections in hexagonal bismuth telluride films on cubic substrates, in-plane lattice mismatches were characterized with accuracy at least 20 times better than using other X-ray diffraction methods, providing clear evidence of 0.007% lateral lattice mismatch, consistent with stress relaxation associated with van der Waals gaps in the film structure.

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REFERENCES

1. E. H. Smith, P. D. C. King, A. Soukiassian, D. G. Ast, and D. G. Schlom, Appl. Phys. Lett. **111**, 131903 (2017). https://doi.org/10.1063/1.4993477, Google Scholar, Scitation, ISI

2. S. L. Morelhão, G. E. S. Brito, and E. Abramof, Appl. Phys. Lett. **80**, 407 (2002). https://doi.org/10.1063/1.1436271, Google Scholar,

3. B. J. Isherwood, B. R. Brown, and M. A. G. Halliwell, J. Cryst. Growth **54**, 449 (1981). https://doi.org/10.1016/0022-0248(81)90498-X, Google Scholar, Crossref

4. S. L. Morelhão and L. P. Cardoso, J. Appl. Phys. **73**, 4218 (1993). https://doi.org/10.1063/1.352827, Google Scholar, Scitation, ISI

5. S. L. Morelhão and L. P. Cardoso, Solid State Commun. **88**, 465 (1993). https://doi.org/10.1016/0038-1098(93)90615-T, Google Scholar, Crossref

6. J. Z. Domagała, S. L. Morelhão, M. Sarzyński, M. Maździarz, P. Dłużewski, and M. Leszczyński, J. Appl. Cryst. **49**, 798 (2016). https://doi.org/10.1107/S1600576716004441, Google Scholar, Crossref

7. Y.-Z. Zheng, Y.-L. Soo, and S.-L. Chang, Sci. Rep. **6**, 25580 (2016). https://doi.org/10.1038/srep25580, Google Scholar, Crossref

8. S. L. Morelhão, L. H. Avanci, A. A. Quivy, and E. Abramof, J. Appl. Cryst. **35**, 69 (2002). https://doi.org/10.1107/S0021889801018921, Google Scholar, Crossref

9. P. Cheng, C. Song, T. Zhang, Y. Zhang, Y. Wang, J.-F. Jia, J. Wang, Y. Wang, B.-F. Zhu, X. Chen *et al.*, Phys. Rev. Lett. **105**, 076801 (2010). https://doi.org/10.1103/PhysRevLett.105.076801, Google Scholar,

10. G. Wang, X.-G. Zhu, Y.-Y. Sun, Y.-Y. Li, T. Zhang, J. Wen, X. Chen, K. He, L.-L. Wang, X.- C. Ma *et al.*, Adv. Mater. **23**, 2929 (2011). https://doi.org/10.1002/adma.201100678, Google Scholar, Crossref

11. J. J. Lee, F. T. Schmitt, R. G. Moore, I. M. Vishik, Y. Ma, and Z. X. Shen, Appl. Phys. Lett. **101**, 013118 (2012). https://doi.org/10.1063/1.4733317 , Google Scholar, Scitation, ISI

12. K. Hoefer, C. Becker, D. Rata, J. Swanson, P. Thalmeier, and L. H. Tjeng, Proc. Natl. Acad. Sci. U.S.A. **111**, 14979 (2014). https://doi.org/10.1073/pnas.1410591111, Google Scholar, Crossref

13. H. Zhang, C.-X. Liu, X.-L. Qi, X. Dai, Z. Fang, and S.-C. Zhang, Nat. Phys. **5**, 438 (2009). https://doi.org/10.1038/nphys1270, Google Scholar, Crossref

14. Y. L. Chen, J. G. Analytis, J.-H. Chu, Z. K. Liu, S.-K. Mo, X. L. Qi, H. J. Zhang, D. H. Lu, X. Dai, Z. Fang *et al.*, Science **325**, 178 (2009). https://doi.org/10.1126/science.1173034, Google Scholar, Crossref

15. Y.-Y. Li, G. Wang, X.-G. Zhu, M.-H. Liu, C. Ye, X. Chen, Y.-Y. Wang, K. He, L.-L. Wang, X.-C. Ma *et al.*, Adv. Mater. **22**, 4002 (2010). https://doi.org/10.1002/adma.201000368, Google Scholar, Crossref

16. H. Steiner, V. Volobuev, O. Caha, G. Bauer, G. Springholz, and V.

https://doi.org/10.1107/S1600576714020445, Google Scholar, Crossref

17. C. I. Fornari, P. H. O. Rappl, S. L. Morelhão, and E. Abramof, J. Appl. Phys. **119**, 165303 (2016). https://doi.org/10.1063/1.4947266, Google Scholar, Scitation, ISI

18. F. Bonell, M. G. Cuxart, K. Song, R. Robles, P. Ordejón, S. Roche, A. Mugarza, and S. O. Valenzuela, Cryst. Growth Des. **17**, 4655 (2017). https://doi.org/10.1021/acs.cgd.7b00525, Google Scholar, Crossref

19. A. Koma, J. Cryst. Growth **201-202**, 236 (1999). https://doi.org/10.1016/S0022-0248(98)01329-3, Google Scholar, Crossref

20. Y. Guo, Z. Liu, and H. Peng, Small **11**, 3290 (2015). https://doi.org/10.1002/smll.201403426, Google Scholar, Crossref

21. L. He, X. Kou, and K. L. Wang, Phys. Status Solidi RRL **7**, 50 (2013). https://doi.org/10.1002/pssr.201307003, Google Scholar, Crossref

22. A. Ghasemi, D. Kepaptsoglou, P. L. Galindo, Q. M. Ramasse, T. Hesjedal, and V. K. Lazarov, NPG Asia Mater. **9**, e402 (2017). https://doi.org/10.1038/am.2017.111, Google Scholar, Crossref

23. A. J. Littlejohn, Y. Xiang, E. Rauch, T.-M. Lu, and G.-C. Wang, J. Appl. Phys. **122**, 185305 (2017). https://doi.org/10.1063/1.5000502,

24. J. Kampmeier, S. Borisova, L. Plucinski, M. Luysberg, G. Mussler, and D. Grützmacher, Cryst. Growth Des. **15**, 390 (2015). https://doi.org/10.1021/cg501471z, Google Scholar, Crossref

25. T. P. Ginley, Y. Wang, and S. Law, Crystals **6**, 154 (2016). https://doi.org/10.3390/cryst6110154, Google Scholar, Crossref

26. Y. Wang, T. P. Ginley, and S. Law, J. Vac. Sci. Technol. B **36**, 02D101 (2018). https://doi.org/10.1116/1.5015968, Google Scholar, Crossref

27. S.-L. Chang, *X-Ray Multiple-Wave Diffraction: Theory and Application* (Springer-Verlag, Berlin, Heidelberg, 2010). Google Scholar

28. S. L. Morelhão and S. Kycia, Phys. Rev. Lett. **89**, 015501 (2002). https://doi.org/10.1103/PhysRevLett.89.015501, Google Scholar, Crossref

29. T. Tanabe, S. Zhao, Y. Sato, and Y. Oyama, J. Appl. Phys. **122**, 165105 (2017). https://doi.org/10.1063/1.4986768, Google Scholar, Scitation, ISI

30. L. Yao, S. Inkinen, O. Pacherova, M. Jelinek, S. van Dijken, and M. Tyunina, Phys. Chem. Chem. Phys. **6**, 4263 (2018). https://doi.org/10.1039/C7CP08449H, Google Scholar, Crossref

https://doi.org/10.1107/S002188980701521X, Google Scholar, Crossref

32. S. L. Morelhão, C. I. Fornari, P. H. O. Rappl, and E. Abramof, J. Appl. Cryst. **50**, 399 (2017). https://doi.org/10.1107/S1600576717000760, Google Scholar, Crossref

33. C. I. Fornari, P. H. O. Rappl, S. L. Morelhão, T. R. F. Peixoto, H. Bentmann, F. Reinert, and E. Abramof, APL Mater. **4**, 106107 (2016). https://doi.org/10.1063/1.4964610, Google Scholar, Scitation, ISI

34. H. Lind, S. Lidin, and U. Häussermann, Phys. Rev. B **72**, 184101 (2005). https://doi.org/10.1103/PhysRevB.72.184101, Google Scholar, Crossref

35. S. L. Morelhão, *Computer Simulation Tools for X-Ray Analysis* (Springer International Publishing, 2016). Google Scholar, Crossref

36. W. L. Bond, Acta Cryst. **13**, 814 (1960). https://doi.org/10.1107/S0365110X60001941, Google Scholar, Crossref

37. J. A. Quilliam, S. Meng, H. A. Craig, L. R. Corruccini, G. Balakrishnan, O. A. Petrenko, A. Gomez, S. W. Kycia, M. J. P. Gingras, and J. B. Kycia, Phys. Rev. B **87**, 174421 (2013). https://doi.org/10.1103/PhysRevB.87.174421, Google Scholar, Crossref