8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Role of multi-scale defect cluster excitations in the two-stage melting transitions of two dimensional Yukawa solids

Lin I, Yen Chiu, Hao-Wei Hu, and Yun-Xuan Zhang
Department of Physics and Center for Complex Systems, National Central University, Taiwan
Email (speaker): lini@phy.ncu.edu.tw

The melting transition of two dimensional (2D) solid is a fundamental physics issue. In additional to the direct first order transition from the solid to the liquid states, two-stage melting transitions through the intermediate hexatic state have been demonstrated experimentally and numerically in various 2D systems with soft core interactions. Examples include magnetic bubble arrays [1], electrons on liquid surfaces [2], monolayer colloidal suspensions in liquids [3], skyrmion systems [4], dusty plasmas [5], and Yukawa systems [6]. According to the well-known KTHNY (Kosterlitz-Thouless-Halperin-Nelson- Yang) theory, the successive emergences of free dislocation and free disclination defects are the keys causing the successive losses of translational and orientational orders in the two-stage melting transitions [7-10].

In addition to the above two types of defects, the recent studies also demonstrated the emergence of defect clusters (DCs) with various sizes in the two-stage melting transition [11,12]. Nevertheless, the classification of different types of multi-scale clusters, the topological pathways for their formation, their roles on deteriorating the structural order and forming crystalline ordered domains (CODs) with various lattice orientations in the two-stage melting transitions are important fundamental issues.

In this talk, using a 2D Yukawa solid as a platform, we report our numerical studies of unraveling the above intriguing unexplored issues [13]. It is found that DCs can be basically classified into: (A) square or rectangular shaped dense DCs composed of free dislocation with anti-parallel polarity, (B) string or ring like DCs composed of disclinations with alternating topological charges, and (C) large DCs composed of the above two types of DCs. The string-like DCs can be further classified into short-sticklike, C-shaped, and other weakly curve string-like DC. Under the conservation of Burgers vectors and topological charges [14,15], different combinations of the six basic processes of the pair generation (I), dissociation (II), recombination (III), propagation (IV), scattering (V), and annihilation (VI) of dislocations, each through thermal shear induced single bond-break-replacement-rotation, govern DC generation, evolution and diminishing. With increasing temperature, the increasing shear motion leads to the intermittent generation and diminishing of mainly type A DCs through types I and VI processes. It deteriorates the long-range translational order but not the orientational order, and leads to the transition from the solid state to the intermediate hexatic state. The successive bond-breaking-reconnection-rotation events caused further increasing temperature facilitate the formation of types B and C DCs through types I to IV processes, and the formation of CODs with different lattice orientations nearby or surrounded by those DCs. It is the key leading to the transition from the hexatic to the liquid phase, which drastically loses the orientational order. In essence, the successive intermittent emergence of small to large multiscale DCs are the keys causing the two-stage solid-hexatic and hexatic-liquid melting transitions. The successive emergences of free dislocations and free disclinations with increasing temperature are just consequences of the multiscale DC clusters excitations, instead of the origins for the two-stage melting transitions, as proposed in the KTHNY theory [7-10]

References

[1] R. Seshadri and R. M. Westervelt, Phys. Rev. B 46, 5150 (1992).
[2] M. A. Stan and A. J. Dahm, Phys. Rev. B 40, 8995 (1989).
[3] Y. Han, N. Y. Ha, A. M. Alsayed, and A. G. Yodh, Phys. Rev. E 77, 041406 (2008).
[4] Huang, T. Schönenberger, M. Cantoni, L. Heinen, A. Magrez,A. Rosch, F. Carbone, and H. M. Rønnow, Nat. Nanotechnol. 15, 761 (2020).
[5] T. E. Sheridan, Phys. Plasmas 16, 083705 (2009).
[6] A. Radzvilavicius, Phys. Rev. E 86, 051111 (2012).
[7] J. Kosterlitz and D. J. Thouless, J. Phys. C 6, 1181 (1973).
[8] B. I. Halperin and D. R. Nelson, Phys. Rev. Lett. 41, 121 (1978).
[9] D. R. Nelson and B. I. Halperin, Phys. Rev. B 19, 2457 (1979).
[10] A. P. Young, Phys. Rev. B 19, 1855 (1979).
[11] Y.-J. Lai and L. I, Phys. Rev. E 64, 015601(R) (2001).
[12] M. Mazars and R. Salazar, Europhys. Lett. 126, 56002 (2019).
[13] Y. Chiu, H. W. Hu, Y. X. Zhang, and Lin I, Phys. Rev. Research, 6, 013288 (2024).
[14] C. H. Chiang and Lin I, Phys. Rev. Lett. 77, 647 (1996).
[15] M. C. Chen, C. Yang and Lin I, Phys. Rev. E 90, 050401(R) (2014).