**INFORMATION ON DOCTORAL THESIS**

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5. Amission decision number 3358/QĐ-ĐHKHTN dated 28/10/2019 by University of Science, Vietnam National University
6. Changes in academic process: No
7. Officical thesis title: Improvements of critical current density of Bi-Pb-Sr-Ca-Cu-O high-$T_c$ superconductor by addition of nano-structured pinning centers
8. Major: Thermophysics
9. Code: 9440130.07
10. Supervisors: Prof. Luu Tuan Tai, Asso.Prof. Tran Hai Duc
11. Summary of the new findings of the thesis:

The explorations of the issue of critical current density and pinning mechanism in Bi-Pb-Sr-Ca-Cu-O superconductors with three types of 0D APC, including Na-substitution, $TiO_2$ nanoparticle addition and $Fe_3O_4$ nanoparticle addition, were carried out. Main results of this dissertation, improvements of $J_c$ in BPSCCO superconductors via the additions of 0D APC was systematically investigated, and summarized as the followings:

For the BPSCCO superconductors with the substitution of Na into Ca site, the dominant pinning mechanism appeared to be temperature independent. The improved flux pinning properties in the Na-substituted samples were induced the growth of point-like pinning and the decline of grain boundary pinning resulting from the Na substitution. Especially, the $\delta l$ pinning was found to be the predominant pinning mechanism responsible for the samples.

For the BPSCCO superconductors with the addition of non-magnetic $TiO_2$ nanoparticles, the $J_c(B)$ of the samples were enhanced by adequate doping contents of $x$ = 0.002, 0.004. The results revealed the extension of the small and large bundle regimes with adequate amounts of $TiO_2$ nanoparticles. The $j(t)$ analyses exhibited that the $\delta l$ pinning was the dominant pinning mechanism in all samples. The normalized

field dependence of $f_p$ was investigated to clarify the influence of $TiO_2$ nanoparticles as normal core point pinning. Additionally, a close correlation between local structural variations and change in $T_c$ of the BPSCCO was investigated.

For the BPSCCO samples with the additions of magnetic $Fe_3O_4$ nanoparticles, the enhancements of $J_c$ were obtained for x = 0.01 and 0.02. The appearance of additional normal core point pinning centers in the doped samples was confirmed by using the Dew–Hughes model. Interestingly, the additions of magnetic nanoparticles were concluded to provide the strongest enhancements of $J_c$ among the methods used in the research.

Motivated by results presented in the dissertation, further studies on BPSCCO superconductors will be carried out. The effects of volume pin – by using nanoparticles with larger size and columnar pin – by adding nanotubes or self-assembled nanorods/nanocolumns are being predicted to play important roles in comparing and understanding possible shifts in pinning mechanism in BPSCCO. Consequently, the key factors to apply nano-technology in the enhancements of flux-pinning properties in type-II superconductors will be obtained.

12. Futher research directions

Based on the research results achieved, in the near future, researchers will continue to study

- Enhance critical current density and the pinning parameters of high-temperature Bi-Pb-Sr-Ca-Cu-O superconducting systems using magnetic nano-materials
- Enhance critical current density and the pinning parameters of $MgB_2$ thin film by irradiation
- Synthesis and superconducting properties improvements of high-entropy superconductors

13. Thesis-related publications

[1] **An T. Pham**, Dzung T. Tran, Duong B. Tran, Luu T. Tai, Nguyen K. Man, Nguyen T. M. Hong, Tien M. Le, Duong Pham, Won-Nam Kang, Duc H. Tran (2021), "Unravelling the scaling characteristics of flux pinning forces in $Bi_{1.6}Pb_{0.4}Sr_2Ca_{2-x}Na_xCu_3O_{10+\delta}$ superconductors", Journal of Electronics Materials 50, pp. 1444-1451.

[2] Dzung T. Tran, **An T. Pham**, Ha H. Pham, Nhung T. Nguyen, Nguyen H. Nam, Nguyen K. Man, Won-Nam Kang, I-Jui Hsu, Wantana Klysubun, Duc H. Tran (2021), "Local structure and superconductivity in $(Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta})_{1-x}(Fe_3O_4)_x$ compounds", Ceramics International 47(12), pp. 16950-16955.

[3] **An T. Pham**, Dzung T. Tran, Ha H. Pham, Nguyen H. Nam, Luu T. Tai, Duc H. Tran (2021), "Improvement of flux pinning properties in $Fe_3O_4$ nanoparticle-doped $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta}$ superconductors", Materials Letters 298, pp. 130015(1-5).

[4] **An T. Pham**, Dzung T. Tran, Linh H. Vu, Nang T.T. Chu, Nguyen Duy Thien, Nguyen H. Nam, Nguyen Thanh Binh, Luu T. Tai, Nguyen T.M. Hong, Nguyen Thanh Long, Duc H. Tran (2022), "Effects of $TiO_2$ nanoparticle addition on the flux pinning properties of the $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta}$ ceramics", Ceramics International 48(14), pp. 20996–21004.

[5] **An T. Pham**, Linh H. Vu, Dzung T. Tran, Nguyen Duy Thien, Wantana Klysubun, T. Miyanaga, Nguyen K. Man, Nhan T.T. Duong, Nguyen Thanh Long, Phong V. Pham, Nguyen Thanh Binh, Duc H. Tran (2023), "Correlation between local structure variations and critical temperature of $(Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta})_{1-x}(TiO_2)_x$ superconductor", Ceramics International 49(7), pp. 10506-10512.

[6] Tran Tien Dung, **Pham The An**, Tran Ba Duong, Nguyen Khac Man, Nguyen Thi Minh Hien, Tran Hai Duc (2021), "Excess Conductivity Analyses in Bi-Pb-Sr-Ca-Cu-O Systems Sintered at Different Temperatures", VNU Journal of Science: Mathematics – Physics 37(4), pp. 1-10.

[7] **An T. Pham**, Thao V. Nguyen, Yen T. Pham, Duc H. Tran, Nguyen K. Man, Dang T. B. Hop (2019), "Effects of $Fe_3O_4$ nanoparticle addition on structural and superconducting properties of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta}$ system", Proceedings The 4$^{th}$ International Conference on Advanced Materials and Nanotechnology, pp. 17-20.

[8] **An T. Pham**, Duc V. Ngo, Duc H. Tran, Nguyen K. Man, Dang T. B. Hop (2019), "Improvements of flux pinning properties in $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta}$ system by Na substitutions", Proceedings The 4$^{th}$ International Conference on Advanced Materials and Nanotechnology, pp. 36-39.

[9] **An T. Pham**, Dzung T. Tran, Luu T. Tai, Nhung T. Nguyen, Nguyen K. Man, Dang T. B. Hop, Phung Manh Thang, Duc H. Tran (2022), "Investigation of flux pinning

properties of the $(Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta})_{1-X}(Fe_3O_4)_X$ superconductors", Proceedings The 12th Vietnam National Conference of Solid Physics and Materials Science, pp. 19-22.

Date: /10/2023

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