Revised Version

Analytical study on holographic superconductors with backreactions

Qiyuan Pan[1,2*], Jiliang Jing[1,2†], Bin Wang[3‡] and Songbai Chen[1,2§]
[1] *Institute of Physics and Department of Physics, Hunan Normal University, Changsha, Hunan 410081, China*
[2] *Key Laboratory of Low Dimensional Quantum Structures and Quantum Control of Ministry of Education, Hunan Normal University, Changsha, Hunan 410081, China and*
[3] *INPAC and Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China*

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Abstract

We employ the variational method for the Sturm-Liouville eigenvalue problem to analytically investigate the properties of the holographic superconductors. We find that the analytic method is still powerful when the backreaction is turned on. Reducing step size in the iterative procedure, we observe that the consistency of results between the analytic and numerical computations can be further improved. The obtained analytic result can be used to back up the numerical computations in the holographic superconductor in the fully backreacted spacetime.

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* panqiyuan@126.com
† jljing@hunnu.edu.cn
‡ wang_b@sjtu.edu.cn
§ csb3752@163.com

I. INTRODUCTION

As a powerful tool to analyse strongly coupled quantum field theories, the anti-de Sitter/conformal field theories (AdS/CFT) correspondence [1–3] states that a d-dimensional weakly coupled dual gravitational description in the bulk is equivalent to a $(d-1)$-dimensional strongly coupled conformal field theory on the boundary. In recent years, this principle has been used to provide some meaningful theoretical insights in order to understand the physics of high T_c superconductors from the gravitational dual [4, 5]. It was found that the spontaneous $U(1)$ symmetry breaking by bulk black holes can be used to construct gravitational duals of the transition from normal state to superconducting state in the boundary theory, which exhibits the behavior of the superconductor [6]. Due to the potential applications to the condensed matter physics, there have been a lot of works studying various gravity models with the property of the so-called holographic superconductor (for reviews, see Refs. [7–9] and references therein).

In most cases, the studies on the holographic superconductors focus on the probe approximation where the backreaction of matter fields on the spacetime metric is neglected. When taking the backreaction into account, it was found that even the uncharged scalar field can form a condensate in the $(2+1)$-dimensional holographic superconductor model [5]. Furthermore, in the p-wave holographic dual models, it was argued that the phase transition that leads to the formation of vector hair changes from the second order to the first order when the gravitational coupling is large enough [10, 11]. There have been accumulated interest to study the holographic superconductor away from the probe limit [12–23]. Recently, the effect of the backreaction has been investigated between holographic insulator and superconductor [24–28].

Almost all works on the holographic dual models away from the probe limit were based on numerical computations. In order to back up numerical results and gain more insights in the effect of the backreaction, a fully analytic study is called for. Refining the analytic matching method developed in [29, 30], Kanno calculated the critical temperature of (3