k-space Microscopy of Bi2Sr2CaCu2O8+ :Fermiology and Many-body Effects
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Citation for published version (APA):
INTRODUCTION

The microscopic mechanism that drives the phenomenon of high temperature superconductivity (HTSC) in the cuprates family, has been the subject of a great debate for almost 22 years. Superconductivity, a phenomena in which the resistance of the material becomes zero below a certain critical temperature, has always attracted much attention within the condensed matter physics community. This interest was all the more great when the HTSC systems pushed critical temperatures above the boiling point of liquid nitrogen (77 K), thereby bringing widespread utilisation of superconductivity a step closer.

The solution of the high $T_C$ puzzle is one of the great challenges facing contemporary condensed matter physics, and an understanding of the mechanism responsible for HTSC can be obtained from studying and investigating their electronic structure, the concepts which deal with band theory describing the ranges of energy that an electron with a particular wavevector is "forbidden" or "allowed" to have. The electronic structure of the system also describes how the electrons interact with each other and with other degrees of freedom of the system. Such complex interactions, in turn, cause many novel phenomena in condensed matter physics such as colossal magnetic-resistance, metal-insulator transitions and superconductivity.

This thesis describes angle-resolved photoemission (ARPES) studies of Bi2212-based high $T_C$ superconductors. This experimental technique is regarded as a powerful tool in studying the electronic structure of materials and is a direct probe of the band dispersion (the energy vs. momentum relation) of the interacting, many body system. This thesis is organised in the following way: in Chapter 2, a brief introduction to the high-temperature superconducting cupra-
tes and an overview of previous ARPES measurements is given, with particular focus on one of the cuprate families, namely, Bi2212-based compounds. In this review we focus on the subjects that become the main interest in our investigation, namely, the Fermi surface topology, the superconducting gap, and the many-body effects observed in the electronic states near the Fermi level. Another part of Chapter 2 deals with a description of the ARPES technique used in the work presented here and how to analyse the data resulting from this technique. The extraction of important quantities for high-temperature superconducting cuprates such as the superconducting gap and the scattering rate are addressed in some detail.

In Chapter 3, we investigate the origin of the shadow Fermi surface (SFS) seen in the Bi2212-based systems, one of the primary features in their fermiology besides the main Fermi surface (MFS). The SFS is known of for more than 12 years and yet its origin is still unresolved. Based on a symmetry argument applied to the relevant electronic states, we devise an experiment that can distinguish between initial and final state effects in the photoemission signal from the main band (MB) and SFS bands. Using this evidence, along with low energy electron diffraction (LEED) data, we are able to offer a complete solution to the shadow Fermi surface issue, proving once and for all that this feature has a structural origin, being due to orthorhombic displacements of Bi and Cu atoms from the initial tetragonal symmetry.

After clearing up the SFS question, we move on to issues related to many-body effects seen in the ARPES data of high $T_C$ cuprates; features commonly referred to as “kinks”. In Chapter 4 we present temperature and momentum dependent measurements on overdoped Bi2212. We choose the overdoped regime for these studies, as it is broadly accepted that the overdoped cuprates are (or are close to being) Fermi liquids in the normal state. This enables us to apply numerical analyses of the data without undue doubt as to their validity, which is not per se the case for lower doping levels. The many-body effects reflect the interaction between the electrons and other degrees of freedom (e.g. lattice vibrations or phonons, magnetic spin fluctuations, etc.). Therefore, by investigating their temperature and momentum dependence in ARPES experiments, it is hoped that one can distinguish with which bosonic degree of freedom the electrons are coupling in the superconducting state of overdoped Bi2212. In this chapter we perform a simple analysis to reveal which interaction is most likely to be responsible for the many-body effects seen in ARPES data from this
compound, and in particular, for \( k \)-locations near the antinode, at the zone face.

Based on the results from Chapter 4, we are able to focus our analysis on the role played by magnetic degrees of freedom, and in particular on the spin-1 resonance mode and the spin fluctuation continuum. Since the simple analysis given in Chapter 4 works well only for conventional BCS superconductors, in Chapter 5 a more elaborate theoretical framework is employed to analyse the data, involving a self-energy which is based on a magnetic spin fluctuation (SF) model. In this model the self-energy has contributions from the spin-1 resonance mode, a spin fluctuation continuum, a Fermi liquid term and a simple offset due to impurities. To match the increased theoretical effort on the data analysis, in Chapter 5 the ARPES data themselves are recorded using multiple polarisations of the exciting synchrotron radiation, thus enabling a significant improvement in the reliability of the data fitting that lies at the heart of the data analysis. Finally, a summary will be presented at the end of the thesis.