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授与した学位	博　士
専攻分野の名称	理　学
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学位授与の要件	自然科学研究科　先端基礎科学専攻 （学位規則第５条第１項該当）
学位論文の題目	Emergence of the Hidden-Order State in URu_2Si_2 Studied by Angle-Resolved Photoemission Spectroscopy （角度分解光電子分光で見た URu_2Si_2 における隠れた秩序状態の発現）
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学位論文内容の要旨

This work investigates the nature of the so-called "hidden-order" transition in URu_2Si_2, one of the long-standing unresolved mysteries in solids, by means of ultrahigh-resolution angle-resolved photoemission spectroscopy. Although thermodynamic properties clearly indicate the existence of a second-order phase transition in URu_2Si_2 at ~ 17.5 K, microscopic characters of the transition, such as the order parameter, the ordering vector, and the type of spontaneous symmetry breaking, have not been identified for more than a quarter century. Although various exotic orders have been proposed theoretically for the hidden order, the information on the evolution of electronic states is currently lacking. The motivation of present work is to uncover the electronic aspects of the "hidden order" by investigating the momentum and temperature dependence of the single-particle spectral functions in URu_2Si_2.

The detail of electronic structures near the Fermi level in URu_2Si_2 was investigated employing state-of-art laser angle-resolved photoemission spectroscopy. When the sample temperature was decreased, the appearance of a narrow dispersive band was detected near the Fermi level only in the ordered state. However, the narrow dispersive band was absent in the Rh-substituted sample. The precise temperature-dependent measurements of the narrow band confirmed that the band appears at the onset of the hidden-order transition. These results strongly suggest that the emergence of the narrow band is the clear signature of the hidden-order transition. The appearance of the narrow band is interpreted to be the modification of electronic periodicity in the ordered state along the k_z direction of the momentum space.

The observation of anomalous fine structures in the single-particle spectral functions obtained for the hidden-order state of URu_2Si_2 is also reported. Ultrahigh-resolution data with sufficient signal-to-noise ratio uncover the existence of a 'splitting' in the narrow dispersive band near the Fermi level. Moreover, a small, dispersionless 'satellite' structure is detected only in the hidden-order phase at the binding energy several meV higher than that of the narrow dispersive band. The narrow dispersive band and the satellite structure shift to lower energies concomitantly; this observation suggests that the satellite is also the signature of the hidden-order state. These observations can be explained neither by ordinary bands nor the development of a *c*-*f* hybridization, implying the existence of previously-unknown many-body effects in the hidden-order state of URu_2Si_2.

Three-dimensional electronic states of URu_2Si_2 were studied by ultrahigh-resolution synchrotron angle-resolved photoemission spectroscopy. The k_z dispersions of electronic structures were studied by the $h\nu$-dependent study. In addition, a highly renormalized electron pocket was observed near the Z point with the photons of 34 eV. Temperature-dependent measurements revealed that this electron pocket becomes gapped and evolves into a narrow band through the hidden-order transition. On the basis of the discussion of the 'back-bending' momentum, the gap is suggested to be particle-hole asymmetric. Moreover, with the photons of 19 eV, the appearance of the narrow dispersive band was detected near the Γ point only in the ordered state. These k_z-dependent data of spectral functions evidence that Fermi-surface gapping and spontaneous breaking of translational symmetry along k_z with the ordering vector of (0, 0, 1) must characterize the hidden-order transition.

This study revealed several electronic signatures of the hidden order and the occurrence of spontaneous translational symmetry breaking upon the transition. These pieces of information should put strong constraints on the scenario of the hidden order and open up a *new route* to understand the nature of the hidden order in URu_2Si_2.

論文審査結果の要旨

本学位論文は，凝縮系科学における謎の一つとされている重い電子系超伝導体URu_2Si_2の17.5Kにおける隠れた秩序相転移の正体を解明する目的で，電子構造を直接観測できる角度分解光電子分光を研究手法として用い，その電子構造の相転移前後での変化を詳細に研究し報告したものである。

URu_2Si_2およびRh置換試料のレーザー光電子分光実験からは，相転移温度以下においてフェルミ準位極近傍に非常にバンド幅の狭い準粒子バンド構造を見いだし，相転移のほぼ消失したRh置換試料において同様の構造が観測されないことから，この準粒子バンドの出現が相転移の電子的な特徴的であることを突き止めた。加えて，より高精度の実験を行うことにより，二つの微細電子構造の観測にも成功し，隠れた秩序相における多体効果との関連を考察した。

更に，隠れた秩序相を特徴づける秩序ベクトルを実験的に明らかにするために，3次元波数空間における電子構造を調べることのできる放射光高分解能光電子分光実験をドイツ・ベルリンの放射光施設において行った。極めて有効質量の重い電子的準粒子バンドを観測し，温度変化の測定により相転移温度以下でこの電子的準粒子バンドにギャップが形成することを見いだした。ブリルアンゾーンk_z方向における測定から，転移温度以下ではk_z方向の並進対称性が破れていることを見いだし，それから隠れた秩序の秩序ベクトルが(1,0,0)であることを示唆した。

以上の結果は，隠れた秩序相転移の正体に対して電子状態の観点から新たな知見を与えたものであり，博士の学位に値すると認められる。