量子幫浦效應、雜訊分析及電子失相行為於低維度傳輸系統

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中文摘要

本論文的研究是針對目前幾個低維度系統的重要議題做探討。首先，我們研究單電子式 Mach-Zehnder (MZ)及雙電子式 Hanbury Brown Twiss (HBT)干涉儀的電流及雜訊的能見度，並操作在量子霍爾效應的狀態下。於 HBT 干涉儀中，電流並沒有 Aharonov-Bohm 振盪，唯一能跟 MZ 干涉儀比較的物理量只有雜訊。MZ 干涉儀的雜訊包含兩個部分: h/e 及 h/2e 振盪，h/2e 振盪因溫度、偏壓及失相率的影響而減少比 h/e 振盪更快。另一方面， HBT 干涉儀的雜訊只包含 h/e 振盪。由直覺的想法會認為雙電子式 HBT 干涉儀的雜訊特性與 MZ 干涉儀中的 h/2e 雜訊振盪(雙粒子效應)有密切相關，然而，結果顯示電子式干涉儀的特性是由電子圍繞磁通量的圈數決定，與粒子數多寡無關，所以 HBT 干涉儀的 h/e 雜訊振盪特性與 MZ 干涉儀中的 h/2e 雜訊振盪特性相似。

接下來我們偏離穩態系統，轉而研究電流及雜訊於量子幫浦所驅動之 MZ 干涉儀。MZ 干涉儀的兩 AC 分束電閘不僅可調整電子的穿透係數並可驅動電子的

流動。相對於傳統的偏壓驅動之 MZ 干涉儀，電流的產生純粹於量子效應，其包含了磁通量無關部分 $I^{(0)}$ 及相關部分 $I^{(\Phi)}$ 。這兩個部份隨著頻率的變化與兩個時間尺度有關，也就是平均傳輸時間及兩臂傳輸時間差。另一方面，$I^{(0)}$ 的震盪振幅隨著頻率增加而增加，而 $I^{(\Phi)}$ 的震盪振幅並不隨頻率改變。溫度效應以指數率快速地減少 $I^{(\Phi)}$ 乃因干涉儀的兩臂非等長。當 MZ 干涉儀的兩分束電閘有相等的穿透係數時，困擾實驗的整流效應變得不再影響系統，也就是此時所量到物理量為純量子幫浦效應。此外，我們探討失相效應於長鬆散時間狀態及短鬆散時間狀態。於這兩種狀態下，電流的磁通量相關部份會因失相因子強度增加而被消減，而電流的磁通量無關部份之消減情形只發生於長鬆散時間狀態。

此外，於 MZ 干涉儀中，不同於電流的是雜訊值總為負值，此為費米子的特性之一。此部分，我們專注雜訊值於低溫及低頻兩個狀態。於低溫的狀態，雜訊的振幅隨著頻率的增加而上升，因著電流及雜訊隨著頻率呈現不同的變化，使得有些區域電流雖為零但是雜訊仍然存在，近一步觀察低頻極限，我們發現無雜訊區可經由調整磁相位及幫浦相位而得之。另一考量，也就是低頻狀態，無雜訊區亦可經由同樣的方法而得，然而溫度的出現，使得雜訊值不再消失。

最後，我們研究量子閘極陣列式幫浦，其結構為一對指狀金屬閘極交錯排列於量子線上，閘極均 AC 偏壓，其保持頻率相同但有相位差。當每陣列的指狀閘極數大於二時，電流的產生轉為因時變 Bragg 反射機制的發生，而不再是光子通道間干涉引起。這樣的解釋可適用於瞬時及非瞬時狀態。

Topics in the Low Dimensional Systems: Effects of Quantum Pumping, Shot Noise and Decoherence

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Abstract

We have investigated the important issues in several low dimensional systems. First, we study the visibilities of the current and the shot noise in the one-particle Mach-Zehnder (MZ) and two-particle Hanbury Brown Twiss (HBT) interferometers. Both electronic systems are implemented in the quantum Hall regime. The possible comparisons between two interferometers are only through the shot noise due to the absence of the Aharonov-Bohm oscillations in the currents of HBT interferometers. The shot noises of MZ interferometers are composed of h/e and h/2e oscillations. The visibilities of h/2e oscillations are decreased with the temperature, the voltage and the dephasing faster than those of h/e oscillations. In the other hand, the shot noises of

HBT interferometers only have h/e oscillations. Unlike the naive intuitions that the properties of shot noises of two-particle HBT interferometers would be related to the two particle effects of h/2e oscillations of MZ interferometers, it is the number of enclosing flux deciding the properties of visibilities, not particle numbers. The variations of h/e oscillations with system parameters in HBT interferometers are similar to those of h/e oscillations of MZ interferometers.

Away from the stationary setups, we study the currents and the shot noises in quantum pump driven MZ interferometers. Two AC beam splitters of MZ interferometers are applied to modulate the electron transmissions and excite the electron flows. Contrary to the voltage driven MZ interferometers, the pump currents composed of the flux-independent part $I^{(0)}$ and the flux-dependent part $I^{(\Phi)}$ are arose from pure quantum effects. Subject to the pump frequency, the oscillations of both parts of currents are related to two time scales, average arm traversal time and the difference of two arm traversal times. In the other hand, the amplitudes of oscillations in $I^{(0)}$ increase with frequency; the amplitudes of oscillations in $I^{(\Phi)}$ are kept constant. The temperature effects only smear $I^{(\Phi)}$ exponentially as a results of the arm asymmetry. The rectification effects could be annihilated as the semi-transparence of beam splitters, i.e. the availability of the true pump currents in MZ interferometers. The effects of the decoherence are studied at conditions with

long and short relaxation times. In both conditions, the flux-dependent part is suppressed as increasing the strength of the dephasing. However, the suppression of the flux-independent part only occurs in the long relaxation time condition.

In contrast to the currents, the shot noises of MZ interferometers just reveal the negative value as a result of fermion nature. The low temperature and the low frequency conditions are considered here. In the low temperature condition, the variations of the shot noises are the oscillations with increasing amplitude as increasing the frequency. The different behaviors of the currents and the shot noises with respective to the frequency lead to the regimes where the shot noises exist although the currents vanish. Taking the adiabatic limit, the noiseless regime could be found by tuning two phases, the magnetic phases and the pumping phases. Otherwise, in the low frequency situation, the noiseless condition is also found while removed as taking into account the influence of the temperature.

Finally, a configuration with finger gate array pump is investigated. A pair of finger gate arrays on the top of a narrow wire are staggered and AC biased with the same frequency but differing by a phase. As the finger gates per array are larger than two, the mechanisms of pump currents become the time-dependent Bragg reflection, not just the processes of the photon-assisted interferences. Such explanations are suitable for both the instantaneous and the non-instantaneous regimes.

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