
Abstract

We have studied the time-dependent quantum transport characteristics in mesoscopic systems (MS) including quantum point contacts (QPC), mesoscopic conducting rings, double-barrier structures, quantum well structures, and SNS junctions.  For a QPC, we have considered its transport characteristics in the presence of a transversely polarized electromagnetic field.  The inelastic scattering that causes the transmitting electrons to make inter-subband and inter-sideband transitions to a subband bottom gives rise to dip-like suppressed features in the dc conductance $G$.  We have proposed an experimental setup for the observation of the features found in this investigation.  We have also proposed another experimental setup for the observation of findings in our previous investigation — when the electromagnetic field considered is longitudinally polarized.

The effects of impurities on the dissipation characteristics of a mesoscopic conducting ring has been studied for the case when the threading magnetic flux is increasing linearly with time.  In the weak impurity regime, two different dissipation characteristics are identified.  These two regimes correspond to situations when the electrons that emanate out of incoherent scatterings have, or does not have, appreciable chance of reaching their classical turning point.  As the impurity becomes stronger, the dc component of the induced current in the ring shows...
strong oscillatory dependences to the chemical potential. These oscillatory behaviors are found to associate closely with the band-structure of a one-dimension crystal. Our results thus provide a consistent theoretical framework describing the continuous cross-over from the Fermi surface dominated (strong impurity) regime to the regime (weak impurity) when contributions from states far below the Fermi surface are important.

We have studied the quantum transport phenomena in a double-barrier structure acted upon by a finite-range time-modulated potential. Depending on the width of the barrier, two possible sets of structures in G can occur, either when \(\mu = m \hbar \omega\) or when \(\mu = E_n \pm m \hbar \omega\). Furthermore, for the latter case, we also obtain the quenching of the resonant transmission found by Wagner, but with a small quantitative modification.

For the effects of a time-modulated potential on the transport through a quantum well, we find in the dc conductance \(G\) Fano-structures when \(\mu = m \hbar \omega\) above the bound state energy in the well. These Fano-structures are broadened, together with the emergence of higher \(m \hbar \omega\) processes, as the amplitude of the time-modulated potential increases. These features are identified as the formation of quasi-bound states.

We have continued our investigation of the effects of a time-modulated potential on the current-phase relation of a super-conductor-normal-metal-superconductor (SNS) junction. A deeper physical understanding has been obtained. The transmitting quasi-particles can be trapped temporarily into an Andreev level by emitting \(m \hbar \omega\). These trapped quasi-particles will continue their contribution to the supercurrent until they are re-excited out of the Andreev level and back into the end-electrodes. Even though these trapping processes contribute over the entire range of the superconducting phase difference \(\phi\), the deeper Andreev level is sharp enough so as to give rise to robust characteristics in the current-phase relation of the junction.

Finally, we have done preliminary exploration on the time-modulated transport characteristics through junctions that has wide-narrow-wide configurations. We have also explored the local-density approximation scheme that will be applied to the systems of our interest.

**Keywords:** quantum transport, quantum point contact, mesoscopic ring, inter-subband transition, inter-sideband transition, Fano structures, Andreev levels.

**Motivations and goals**

Mesoscopic systems [1-2] are of great importance due to their potential technological applications and due to the unique set of physical phenomena they exhibit. More recently, the time-dependent phenomena in mesoscopic systems have attracted much attention [3-12]. It is because the time-dependent phenomena could probe deeper into the dynamical aspect of the physics of the systems. In addition, the effects of photons on electron transport is of practical importance.

In our previous studies on the transport characteristics in narrow constriction, we found that the one-dimensional subband structures support the existence of quasi-bound states (QBS)[13]. These QBS are formed at energies just below a subband bottom. The finite number of subbands in the system and the tunability of the dimension of such system together substantiate the significance of the QBS. It is a key factor for the quantum transport phenomena in mesoscopic systems. Thus we opt in this project to investigate the various manifestation of the QBS features in the time-dependent transport phenomena.

The time-dependent fields we considered include gate-potentials, and transversely polarized electromagnetic fields. We compare the characteristics due to QBS formed just below a subband bottom, as in the cases of QPCs; or QBS formed from resonant states, as in the case of a double-barrier structures; and QBS formed from true bound states, as in the case of a quantum well, or a SNS junction. Through these studies, we aim to establish a general picture for the QBS features.

Another reason that makes mesoscopic physics of fundamental interest is that it allows the issue of decoherence to be studied experimentally. This is essentially why that a mesoscopic conducting ring acquires its importance and attentions in the recent past. [14-17] Most of the theoretical discussions and predictions for the properties of such a mesoscopic ring, threaded by a magnetic flux that changes linearly in time, have assumed an adiabatic picture, that is, describing the time-evolution of the quantum states in terms of the instantaneous eigen-states of the system. We feel that the time-evolution of the states should be treated more carefully. Furthermore, the incoherent processes were essentially described in terms of relaxation times. This relaxation-time approach, however, cannot naturally re-introduce those electrons suffered from incoherent scattering back to the system. Therefore we choose to bring to this problem our insight obtained from studies in time-dependent phenomena of other mesoscopic systems. Our purpose is to help establish a sound theoretical basis for the study of mesoscopic rings and to clarify some of the recent controversies among researchers.

---

*E-mail address: cschu@cc.nctu.edu.tw*
\section*{Results and discussions}

The effect of a transversely polarized electromagnetic field on the transport characteristics of a QPC is studied using a generalized scattering-matrix method, which has incorporated a time-dependent mode-matching scheme. The transverse field induces coherent inelastic scatterings that include both intersubband and intersideband transitions. These scatterings give rise to the dc conductance $G$ a general suppressed feature that escalates with the chemical potential. In addition, particular suppressed features--the dip structures--are found in $G$. These features are recognized as the quasi-bound-state (QBS) features that arise from electrons making intersubband transitions to the vicinity of a subband bottom. For the case of larger field intensities, the QBS features that involve more photons are more evident. These QBS features are closely associated with the singular density of states at the subband bottoms.

For the observation of these features, one must be careful about the bolometric effect, especially in the end-electrode regions. Therefore the end-electrodes have to be kept out from the time-modulated field. Hence we propose to generate the transversely polarized field by biasing the split-gates with an ac bias source. The split-gates are also negatively biased in order to define the QPC electrostatically. For the ac bias source, if the frequency is of order 10GHz, devices such as IMPATT diodes is available.

In the case of a mesoscopic ring, two dissipation characteristics are obtained when the impurity is weak. The first regime corresponds to the situation when the electrons that eminate out of incoherent scatterings, and move along the direction of the induced electric field, have appreciable chance of reaching their classical turning point. In this regime, the dissipation is not Ohmic-like and the dc current component in the ring increases with the Fermi energy. In the second regime, most of the electrons that eminate out of incoherent scatterings, and move along the direction of the induced electric field, have negligible chance of reaching their classical turning point. In this regime, the dissipation is Ohmic-like while the dc current component becomes independent of the Fermi energy. However, in this latter regime, we find that the ac current component, with a period of $1/\omega$, in the ring is the same as the adiabatic result. When the impurity is strong, the dc component of the current shows strong oscillatory behavior with respect to the Fermi energy. This can be understood from the one-dimensional band structure.

In a double-barrier structure, we consider the effects of a time-modulated potential. When the barrier width $L$ is small such that the resonant level is poorly defined, we find that there are dip structures in $G$ at the energies $\mu = m \hbar \omega$. However, when $L$ is very large such that the resonant levels are very well defined, there are additional peak in $G$ at energies $\mu = E_{n} + m \hbar \omega$. The cross-over between these two limiting regimes, with intermediate $L$s, show structures at all these incident energies. Our results show the competitive in the formation of QBS. Also in looking for the quenching structures in the resonant peak, we find that the quenching effect occurs only for sufficiently sharp resonance peak.

In a quantum well structure, we consider the effects of a time-modulated potential when the transport is parallel with the well width. The transmitting electrons can be trapped by the bound states in the well if their incident energy is at $m \hbar \omega$ away from the bound state energies. This trapping process gives rise to Fano-structures in the dc conductance $G$. The evolution of the $G$-structure from the Fano-like to the dip-like structure is studied when the position of the time-modulated potential is changed. Our results show that the dip structure is the more robust structure indicating the existence of QBS, even though in principle we should go after the peak, or the pole in $G$.

In a SNS junction, and in the presence of a time-modulated potential in the normal region, the current-phase relation shows dip structures that are found to originate from the trapping of the transmitting quasi-particles by the deeper Andreev levels in the junction. The trapping in the shallower Andreev level does contribute but cannot give rise to sharp characteristics. Because its contribution is spread over a wide $\Delta \phi$ range.

\section*{Self-evaluation of project results}

In this project, we have studied the time-dependent quantum transport in various mesoscopic systems. New understanding has been obtained about the importance and the manifestation of the trapping process. Part of these results have been presented in the 1999 annual meeting of the Physical Society of the Republic of China.[18] Two papers are published in the Chinese Journal of Physics, and four more papers are either being submitted or to be submitted.[19] The issues studied are of current interest to the mesoscopic communities and the results obtained are of importance to the further development of the field.

\section*{五、参考文献}


[18] Conference papers:
The 1999 annual meeting of the Physical Society of the Republic of China

H.C. Liang and C.S. Chu, "Effects of incoherent processes on the quantum transport through a finite-range time-modulated potential."
Oral session: Da4

C.S. Tang and C.S. Chu, "Time-modulated effects in a narrow constriction: from photon-induced transport to ac response"
Oral session: Da5

M.T. Liu and C.S. Chu, "Effects of incoherent processes on the dc current induced by a linearly time-dependent ring"
Oral session: Da6

[19] Published and submitted papers:


C.S. Chu and H.C. Liang, 1999, "Quantum transport through a quantum well in the presence of a finite-range time-modulated potential"

M.T. Liu and C.S. Chu, 1999, "Dissipation in a partially coherent flux-driven ring"
(submitted)

C.S. Tang and C.S. Chu, 1999, "Coherent quantum transport in the presence of a finite-range transversely polarized time-dependent field"
(submitted)

M.T. Liu and C.S. Chu, 1999, "Effects of an impurity on the dissipation of a mesoscopic ring"
(submitted)

H.C. Liang and C.S. Chu, 1999, "Current-phase relation of a SNS junction in the presence of a time-modulated potential"
(submitted)

---

*E-mail address: cschu@cc.nctu.edu.tw*