Time Resolved Potential Measurement At Quantum Point Contacts Under Irradiation Of Surface Acoustic Burst Wave

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Abstract. We evaluate the time-dependent potential at some quantum point contacts under irradiation of surface acoustic burst wave. The time and space dependences of the potential wave allow us to separate direct surface acoustic wave from other indirect acoustic wave and electromagnetic crosstalk. The technique can be used to separate the left- and right-moving acoustic waves.

Keywords: Surface acoustic wave, Quantum point contact, Time-dependent potential, Interdigital transducer.
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INTRODUCTION

Monochromatic surface acoustic waves (SAWs) generated by an interdigital transducer (IDT) provide unique electron transport in piezoelectric semiconductors. Modulation of SAWs in time and space is attractive for flexible and dynamical control of electrons. For instance, moving potential waves induced by SAWs carry single electrons and spins in a narrow constriction [1,2]. On-demand single electron transport is expected with few cycles of SAWs [3]. SAW phonons can be used as a monochromatic excitation source for electrons in quantum dots [4]. When an electron experiences a short period of SAWs, coherent and/or incoherent control of electronic states is expected. However, practical problems for generating SAW burst arise from interference of SAW in a semiconductor device and crosstalk from electromagnetic wave (EMW) [5,6].

In this work, we employed time domain analysis to separate each contribution. The time-dependent potential measurements were carried out at some quantum point contacts (QPCs) separated by a fraction of SAW wavelength. This scheme allows us to separate EMW and SAW, more importantly left- and right-moving SAWs. The technique will be useful in investigating potential wave and interferences in mesoscopic devices.

EXPERIMENTS

Figure 1(a) shows a schematic device structure consisting of QPCs at the center and IDTs on the left (IDT1) and right (IDT2). The QPCs are formed in an AlGaAs/GaAs heterostructure, while IDTs are fabricated on the GaAs substrate. Each IDT has M = 100 pairs of metal fingers with the period $\lambda = 0.8$ μm. Scanning electron micrographs (SEMs) of a control device are shown in Figs. 1(b) for an IDT and 1(c) for QPCs. While the pattern in Fig. 1(c) was designed to form a double quantum dot, we activated one of the QPCs (QPC1 and QPC2, separated by 0.24 μm in the design) in the following experiments. All experiments were performed at around 5 K in helium gas environment.

Two rf burst waves, V_{IDT} and V_{QPC}, whose waveforms are schematically shown in Fig. 2(a), were applied to IDT1 and a source contact of QPCs, respectively. The pulse patterns with N = 50 period at the carrier frequency $f_0 = T_0^{-1}$ = 3.18 GHz are repeated by a sufficiently long period $T_r = 2500T_0$. The pulse pattern for V_{QPC} is delayed with respect to that for V_{IDT}, with the delay time t_{d} varied in a step of $0.05T_0$.

Application of the burst wave to IDT1 generates SAW burst with $M + N$ = 150 periods, which propagate through the QPCs after a traveling time of about $106T_0$. We investigate time-evolution of the

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potential at the QPCs adjusted in the tunneling regime. The time-dependent barrier potential is demodulated by applying V_{QPC} between the source and the drain of the QPC. The QPC works as a multiplier because the current variation is given by a product of the bias voltage and the transmission probability through the barrier [7]. The dc (averaged) current I_{det} as a function of the delay time t_d reflects the time dependent potential.

Figures 2(b) and 2(c) show the derivative dI_{det}/dt_d traces obtained with QPC1. We observed $I_{det}(t_d)$ oscillating with the period T_0, which is so compressed in Fig. 2(b) that only envelope function can be recognized. The triangular envelop around $t_d \sim 0$ (marked by EMW) is associated with the electromagnetic crosstalk. The direct SAWs (dSAW) are detected at around $t_d/T_0 \sim 100$, which corresponds the spacing between the IDT1 and the QPC (106λ). Other indirect SAWs after reflection at etching steps and metal patterns can be seen in subsequent time (not shown). In this way, these waves are clearly separated in the time domain measurement.

We observed similar envelope function by using QPC2, but the phase evolutions are different as summarized in Fig. 2(c). The phase for EMW is independent of the QPCs, which manifests EM crosstalk in the device. In contrast, the finite phase difference ($\delta \sim 0.25$) for dSAW is consistent with the spatial separation (0.24 μm) relative to the wavelength (0.8 μm), and ensures that the SAW propagates from the left to the right. We have conformed that SAW propagates from the right to the left, when SAW is generated from IDT2. Even when left- and right-moving waves interfere, our analysis with two QPCs can separate the two contributions in principle. This will be useful in analyzing propagating potential waves in mesoscopic structures.

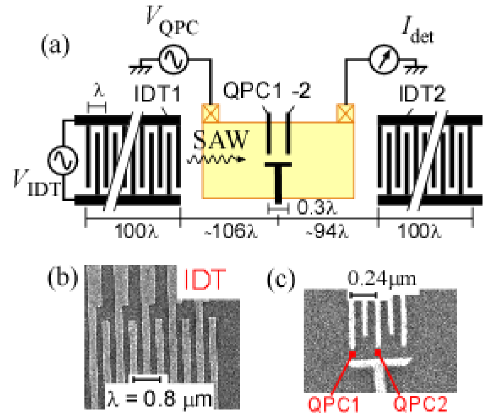

FIGURE 1. (a) Schematic device structure and measurement setup. One of the QPCs is activated for local potential measurements. (b) and (c) SEMs of an IDT and QPCs.

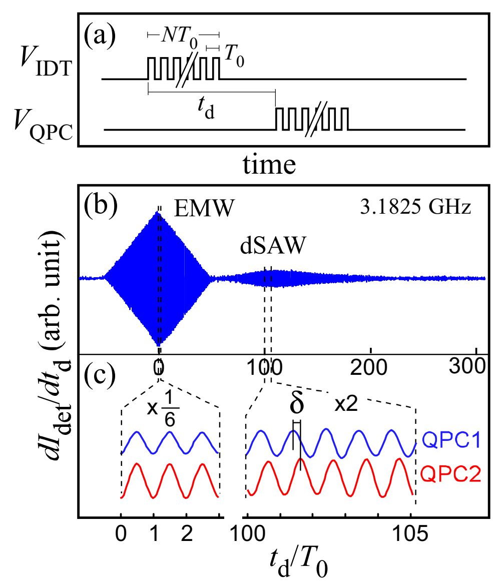

FIGURE 2. (a) The rf burst waveforms applied to an IDT and a QPC. (b) and (c) Delay time (t_d) dependence of the QPC current (I_{det}), reflecting the time-dependent potential due to EMW and direct SAWs (dSAW).

SUMMARY

In summary, we demonstrated time domain analysis of potential wave originating from SAW and EMW. The technique can be used to identify interefence from other structures in the device.

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