Measurement of Thermoelectric Power in Unidirectional Lateral Superlattices

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Abstract. We have measured thermoelectric power in unidirectional lateral superlattices (ULSLs). The oscillations due to the Landau quantization in the longitudinal thermoelectric power S_{xx} exhibit marked amplitude modulation, analogous to but more pronounced than the amplitude modulation of the Shubnikov-de Haas oscillations in the resistivity ρ_{xx}. The semiclassical commensurability oscillations are not evident in S_{xx}, but are expected to be more apparent in the transverse component with the temperature gradient applied perpendicular to the principal axis of ULSLs, underlining the qualitative difference between the resistivity and the thermoelectric power in the way the anisotropy manifests itself.

Keywords: thermoelectric power, lateral superlattice, commensurability oscillations
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A unidirectional lateral superlattice (ULSL) is a prototypical electron system with artificial anisotropy; externally imposed modulation of an electrostatic potential, usually well approximated by the sinusoidal form $V(x) = V_0 \cos(2\pi x/a)$, introduces a simple and well-defined anisotropy between x and y directions into the two-dimensional electron gas (2DEG). Magnetotransport properties of ULSLs have been studied so far mainly through the measurement of the resistivity $\rho_{\alpha\beta}$ $(\alpha,\beta = x,y)$. Arguably the most prominent phenomenon observed in ULSLs is the commensurability oscillations (CO) [1], the magnetoresistance oscillations originating from the commensurability between the period a of the ULSL and the cyclotron radius $R_c = \hbar k_F/eB$. Similar commensurability effects are theoretically predicted [2] for the thermoelectric power $S_{\alpha\beta}$ in ULSLs. To the knowledge of the present authors, however, thermoelectric power of ULSLs has not been experimentally explored thus far. In the present paper, we report our measurement of the thermoelectric power performed on ULSLs. Note that CO is a typical anisotropic phenomenon, taking place predominantly in the resistivity along the principal axis of the modulation ρ_{xx}. We will see that CO is expected to appear principally in S_{xy} rather than in S_{xx}.

Sample devices are prepared from a GaAs/AlGaAs 2DEG wafer with the electron density n_e=2.1×10^{15} m^{-2} and the mobility μ=77 m^2/Vs. Periodic potential modulation is introduced via strain-induced piezoelectric effect [3] by a grating of negative electron-beam resist placed on the surface [4]. As shown in Fig. 1, the devices contain sections with (ULSL) and without (plain 2DEG) the modulation in series, the latter serving as the reference. Figure 1 depicts the configurations for the measurements of the resistivity (a) and the thermoelectric power (b), (c). We employ current-heating technique in the thermoelectric power measurements [5, 6]: gradient in the electron temperature $\Delta T_e = T_{\rm high} - T_{\rm low}$ is introduced by passing an ac heating current I_h (=10−100 nA, f=13 Hz) through the section opposite to the section to be measured and the generated voltage having the frequency $2f$ is detected, noting that $\Delta T_e \propto I_h^2$. The measurements are performed in a dilution fridge at $T\simeq$20 mK.

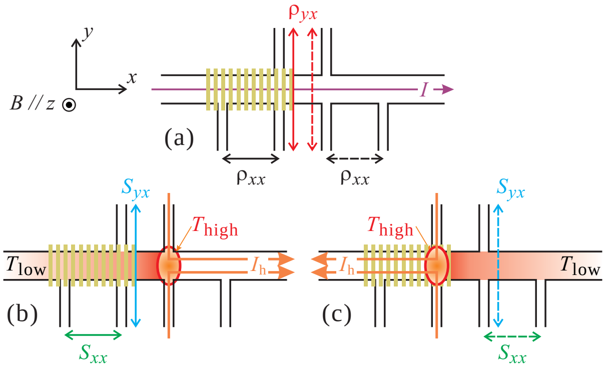

FIGURE 1. Schematic diagrams illustrating the measurement configurations for (a) longitudinal ρ_{xx} and transverse ρ_{yx} resistivity for both ULSL and plain 2DEG sections, (b) longitudinal S_{xx} and transverse S_{yx} thermoelectric power for the ULSL section, and (c) S_{xx} and S_{yx} for the plain 2DEG section. Measurements for the ULSL and the plain 2DEG sections are represented by solid and dashed lines, respectively.

In Fig. 2, we compare resistivity ρ_{xx} (a) and the longitudinal S_{xx} (b) and transverse S_{yx} (c) thermoelectric power, measured in a ULSL with the period a=184 nm and the modulation amplitude V_0=0.3 meV. It can be seen that the semiclassical component observed in (a), namely the slower oscillations that survive up to high temperatures (see the 4.2 K trace), is not discernible in

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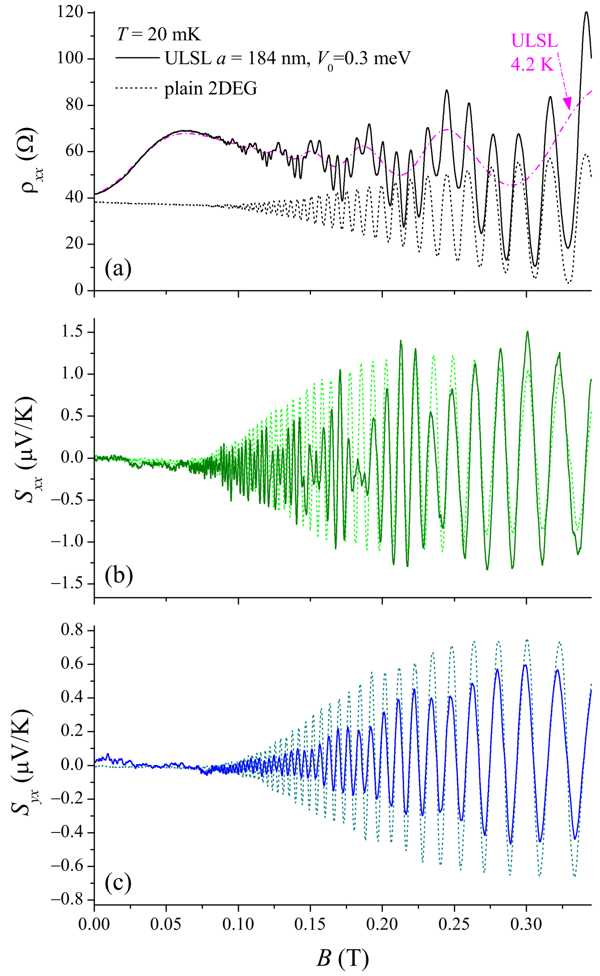

FIGURE 2. Magneto-transport coefficients measured at 20 mK. (a) Longitudinal resistivity ρ_{xx}. (b) Longitudinal thermoelectric power S_{xx}. (c) Transverse thermoelectric power S_{yx}. ULSL and plain 2DEG sections are represented by solid and dotted curves, respectively. ρ_{xx} at 4.2 K is also shown in (a) (dot-dashed curve).

(b). On the other hand, the quantum oscillations corresponding to the Shubnikov-de Haas (SdH) oscillations (the faster oscillations) with modulated amplitude [7] are observed in (b), even clearer than in (a) especially at lower magnetic fields, attesting to the high sensitivity of the thermoelectric power to the small changes in the density of states (DOS). The oscillations of S_{yx} shown in (c) also exhibit amplitude modulation, albeit with much smaller magnitude.

The unidirectional periodic potential modulation affects the magnetotransport coefficients via two different routes: the band contribution and the collisional contribution [8]. The former is the dominant contribution, responsible for the semiclassical oscillations, and affects only the *y* component of the conductivity σ_{yy}. By contrast, the collisional contribution, which results from the modulation of DOS and therefore affects the SdH oscillations, is isotropic. Noting that σ_{xx}, $\sigma_{yy} \ll \sigma_{yx}$ in 2DEGs subjected to a perpendicular magnetic field, $\rho_{xx} \simeq \sigma_{yy}/\sigma_{yx}^2$ is sensitive to σ_{yy}, hence to the band contribution. The thermoelectric power tensor is given by the product of the resistivity tensor $\hat{\rho}$ and the thermoelectric conductivity tensor $\hat{\varepsilon}$ [9], and with $\rho_{xx}, \rho_{yy} \ll \rho_{yx}, \rho_{xy}$, we have

$$\begin{pmatrix} S_{xx} & S_{xy} \\ S_{yx} & S_{yy} \end{pmatrix} \approx \begin{pmatrix} \rho_{xy}\varepsilon_{yx} & \rho_{xy}\varepsilon_{yy} \\ \rho_{yx}\varepsilon_{xx} & \rho_{yx}\varepsilon_{xy} \end{pmatrix}. \qquad (1)$$

The tensor $\hat{\varepsilon}$ is related to the energy derivative of the conductivity tensor $\hat{\sigma}$ by the Mott relation $\hat{\varepsilon} \propto d\hat{\sigma}/dE$ (applicable for thermoelectric power measured by the current-heating technique [6]). It turns out, therefore, that the longitudinal thermoelectric power S_{xx} is insensitive to the band contribution. Equation (1) reveals that *xy* component of the thermoelectric power, S_{xy}, is expected to be more sensitive to the band contribution. It is worth pointing out that S_{xy} can be quite different from S_{yx} (shown in Fig. 2) in anisotropic systems with $\sigma_{xx} \neq \sigma_{yy}$, as can be seen from Eq. (1) and the Mott relation. The measurement of S_{xy} requires a sample in which the temperature gradient can be introduced in the *y* direction.

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