Locally-Strain-Induced Heavy-Hole-Band Splitting Observed in Mobility Spectrum of p-Type InAs Grown on GaAs

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High-quality Be-doped InAs layer grown by molecular beam epitaxy on GaAs substrate has been examined via magnetotransport measurements and high-resolution quantitative mobility spectrum analysis (HR-QMSA) in the range of 5–300 K and up to 15 T magnetic field. The results show four-channel conductivity and essential splitting of the most populated hole-like channel below 55 K. It is concluded that origin of such effect results from the locally strain-induced interlayer, which direct observation is difficult or impossible via alternative techniques. Based on the magnetotransport data analysis, the multilayer model is proposed, which is implemented into nextnano simulation, giving the proof of the argumentation correctness. These results indicate potential usefulness of HR-QMSA technique even in the degeneration statistic regime.

The A^{III}B^{V} binary compounds with approximately 6.1 Å lattice constant are currently under the great interest of both research groups and manufacturers of advanced electronics. There are many reasons for the 6.1 Å family popularity. The most important is the extraordinary flexibility for bandgap engineering achieved in the infrared energy range via compound alloying and the reduction of dimensionality. Therefore, a wide range of high-speed and low-power devices can be realized, taking the advantage of GaAs, InSb, and InAs properties. In particular, a special attention is devoted to ultrathin layers and low-dimensional objects made of InAs, for example, quantum dots, nanowires, topological insulators, and quantum wells. Indium arsenide forms an active layer in various optoelectronic devices, such as quantum cascade lasers or infrared detectors. Current application of InAs also includes Hall sensor devices and high-electron-mobility transistors (HEMTs) in which transport properties are extremely important. As a result, more and more detailed knowledge about this compound and its interfaces is still needed for the design of complex structures meant for applications.

Especially, the precise description of electrical carrier transport in multilayered structures is a key factor in the device fabrication. Here, the great progress has been made, in which the possibility of separated-conductivity-channels observation plays an important role. The separation of different contributions to the electrical conductivity has become possible through a technique known as the mobility spectrum analysis (MSA). This method is especially interesting for the characterization of valence bands (VBs) because the interpretation of measurement data obtained for p-type channels is much more demanding than for data collected for transport via normally separated conduction band. Therefore, there is a relatively small number of literature reports, where multichannel p-conduction is analyzed and, for example, light-hole effective mass mlh or hole mobility μh versus temperature are presented.

In this article, we present the detailed study on electronic carrier transport in highly doped p-type InAs layer grown on the GaAs semi-insulating substrate. Structure uniformity has been analyzed using the secondary-ion mass spectrometry (SIMS) and highly symmetrical four-terminal electrical devices have been fabricated using the photolithography (PL) technique. Resistance and Hall effect have been measured in the temperature range of 1.5–300 K at magnetic fields up to 16 T. The high quality of obtained data enabled us to apply the very precise variant of MSA method, the so-called high-resolution quantitative mobility spectrum analysis (HR-QMSA). We identified up
to four distinct conductance channels at low temperatures, one related to electrons, second one to light holes, and two to the metallic transport in the heavy-hole band. The last observation has been related to the gradual reduction of strain caused by the lattice mismatch on the InAs/GaAs interface. This interpretation has been supported by the comparison of experimental data with the numerical simulations performed for different temperatures, using the Nextnano code.

The 2 μm p-type InAs epilayer was grown on (001)-oriented semi-insulating epi-ready GaAs substrate via RIBER Compact 21-DZ solid-source molecular beam epitaxy (MBE) system. The layer was deposited on 250 nm-thick GaAs smoothing buffer and high quality of the growth with minimal residual strain has been indicated by X-ray diffraction (XRD) measurement and Raman spectroscopy analysis. Details of the growth procedure and basic characterization have been published elsewhere. The InAs layer studied here was doped with Be-dopant of concentration \( \approx 2 \times 10^{18} \text{ cm}^{-3} \) and the doping uniformity has been checked via SIMS analysis using CAMECA SC Ultra system, with depth resolution below 1 nm. The Ga, In, C, O, and Be intensities were recorded versus measurement time. Knowing the thickness of the InAs layer from HR-SEM results, we determined the sputter rate and depth profile. The results are shown in Figure 1a, in which the intensity signal is converted into the volume concentration as indicated on the right-hand axis.

Data show that the sample is uniformly doped with beryllium. Be, as a light element, can be mixed into the sample during the ion bombardment more effectively than heavier elements such as In. Note that the Be decay length is quite large. However, it depends strongly on the impact energy, so the observed uniformity of distribution is not a SIMS-related artifact. The concentration of carbon and oxygen atoms inside the layers was found to be below the detection limit \( (10^{16} \text{ atoms cm}^{-3}) \) and \( 3 \times 10^{16} \text{ atoms cm}^{-3} \), respectively. Nevertheless, monitoring of these signals allowed us to localize the buffer layer position. Obtained results confirm the assumed architecture of our sample and proof the high homogeneity of the Be-dopant profile, which is important for the MSA.

The application of the HR-QMSA method requires very precise Hall-effect measurements; therefore, the special attention has been devoted to the fabrication of highly symmetrical samples in the van der Pauw (vdP) geometry (Figure 1b). Moreover, it guarantees subtraction of most parasitic effects added to the Hall effect, and ensures better data symmetrization than, for example, “hall bar” geometry. In our vdP case, the four-terminal devices have been defined lithographically using AZ 4533 photoresist and NaOH water solution as a developer. The gold contacts were made by electrolytic deposition using the 1.2% KAu(CN)₂ water solution under 350–375 μA cm⁻² current density. In the following step, the target cloverleaf shape has been obtained in wet etching process. The surface outside the covered shape was etched down to the GaAs substrate using the orthophosphoric acid citric acid: hydrogen peroxide-water (molar ratio: 1:1:4:16) solution and 0.4 mol dm⁻³ hydrochloric acid water solution. Finally, gold wires have been bonded to contact areas. The photoresist has not been washed out after the etching stage, to reduce aging effects by reducing the rate of uncontrolled oxidation.

For the MSA, not only the shape of a sample is important but also the linearity of electrical response. Therefore, our devices have been electrically pre-examined in 300 K to check the symmetry and the electrical contact quality by current–voltage linearity test in the voltage range from -150 to +150 mV. All of the contact pairs gave linear response on voltage bias, where determinacy coefficient for linear function was better than \( R > 0.999 \). Using excitation direct current \( I_{\text{exc.}} = 500 \mu\text{A} \), the dissipated power was lower than 0.1 mW, as required. Sample resistivity and Hall-effect measurements were performed using a Keithley Source Meter 2400 and Keithley 2182A for voltage measurements. Equally important is the homogeneity of magnetic field. Therefore, for the purposes of this study, the superconducting 16T Cryogen-Free Magnet System (CFM16T), made by Cryogenic Ltd., has been used in which magnetic-field homogeneity ensures \( \leq 0.1\% \) total variation over 10 mm sphere diameter.

In this system, the Hall sample is placed on the special holder inside the variable temperature insert (VTI), directly in the circulating high-purity helium, which is kept at a constant pressure. Such environment ensures very good thermal conductivity and in consequence the required temperature stabilization (\( 2\sigma \) in the order of 6–20 mK, for 5–300 K), monitored by CERNOX sensor. Our measurements have been performed over the ±15 T range for each temperature in the so-called Step Scan mode. To assure the proper sample temperature, before each magnetic field scan sequence, at least 20 min-long stabilization
have been applied. The ΔB steps have been chosen properly for uniform adjustment into log10 scale, namely ten points on each decade. For being ensured that the magnetic field is stable, we used 90 s stabilization time before each data collection of all 12 configurations in the vdP method. The results for two of these resistances are shown in Figure 2.

As it is seen, the $R_{4\text{-point}}$ and the $R_{H(ij)}(B) \times B$ curve families exhibit a high smoothness in the whole ranges of magnetic field and temperature. Moreover, the corresponding surfaces obtained for the opposite magnetic fields direction (data not shown) behaved in the highly symmetrical and antisymmetrical manner, as required by vdP method and what is important in mobility spectra calculation step. Therefore, we conclude that the sample was electrically homogeneous in agreement with SIMS analysis, as discussed earlier. Most importantly, the $R_{4\text{-point}}$ resistance is clearly nonmonotonic as a function of magnetic field and Hall resistances reveal strong nonlinearities. It is characteristic for the multicalrier transport in semiconductors and can be analyzed by the mobility spectrum method.

The main concept of mobility spectrum relies on the transformation of measurement data from the magnetic field ($B$) domain into the mobility ($\mu$) domain. The general idea of such calculations is to obtain the conductivity tensor components $\sigma_{xx}(B)$ and $\sigma_{xy}(B)$ using experimental Hall constant $R_{H1}(B)$ and sheet resistance $R_s(B)$ values, according to the following relations\(^\text{[13]}\)

$$
\sigma_{xx}(B) = \frac{R_s(B)}{R_s^2(B) + R_{H1}^2(B)B^2}, \quad \sigma_{xy}(B) = \frac{R_{H1}(B)B}{R_s^2(B) + R_{H1}^2(B)B^2} \quad (1)
$$

These coupled expressions contain information about all carriers present in the sample according to the discrete mobility transform equations\(^\text{[23]}\)

$$
\sigma_{xx}(B) = \sum_i \frac{S_p(\mu_i) + S_n(\mu_i)}{1 + \mu_i^2 B^2}, \quad \sigma_{xy}(B) = \sum_i \frac{[S_p(\mu_i) - S_n(\mu_i)]\mu_i}{1 + \mu_i^2 B^2} \quad (2)
$$

where $S_p(\mu)$ and $S_n(\mu)$ are the hole and electron mobility spectra (i.e., hole and electron conductivities in the mobility domain). The symbols $p_n(\mu)$ and $n_\mu(\mu)$ are hole and electron sheet densities, respectively, and $e$ is the electronic charge. Therefore, to identify each type of the multiple carriers contributing to transport, we have to obtain mobility distributions $S_p(\mu_i)$ or $S_n(\mu_i)$, using the appropriate numerical methods. Here, $\mu$ is negative for electrons ($e < 0$) and positive for holes ($e > 0$) in accordance with the generally accepted convention.

The basic algorithms for that purpose have been described by Beck and Anderson;\(^\text{[23]}\) however, they might be insufficient for a proper recognition of multichannel conductivity in semiconductor devices.\(^\text{[24]}\) Fortunately, a significant progress has been made in recent years and new, improved methods have been successfully tested on many different material systems.\(^\text{[25,26]}\) Here, we applied HR-QMSA,\(^\text{[15]}\) which previously gave excellent results for proper recognition of carrier transport through valleys in non-intentionally doped GaSb substrate.\(^\text{[27]}\) Results of HR-QMSA method applied to our data are shown in Figure 3.

Clearly, we identify the four distinct mobility spectra peaks, which contribute to the total conductivity tensor. One is electron-like (denoted $E_1$), and three others are hole-like (denoted $H_1$, $H_1'$, and $H_2$). Note that $H_1'$ peak disappears for higher temperatures $T > 55$ K or rather merges with stronger $H_1$ contribution. Note also that $H_2$ feature, which corresponds to carriers with the highest mobility, is rather weak. From the obtained mobility spectra, we calculated the partial conductivity $\sigma_j$, mean Hall mobility $\mu_j^H$, and sheet carrier concentration $N_j$ associated with the $j$th conductivity peak, using the following formulas

$$
\sigma_j = \sum_i S_i(\mu_i), \quad \mu_j^H = \frac{1}{\sigma_j} \sum_i \mu_i S_i(\mu_i), \quad N_j = \frac{\sigma_j}{e} \quad (3)
$$

Results, as a function of temperature, are shown in Figure 4. The densities $N_j$ and corresponding mobilities $\mu_j^H$ are collected on the left-hand side, and the stack area plot of partial conductivities $\sigma_j$ is presented on the right-hand side.
Both plots reveal at least four characteristic temperature sets. At $T < 30$ K (Set I) and for $T > 150$ K (Set IV), all conductivities, despite small fluctuations, decrease monotonically and the mobility spectra peaks become wider with increasing $T$. This is not the case for the intermediate range of temperatures (Sets II and III), in which the partial conductivities fluctuate very strongly. At the same time, the width of dominant $H_1$ contribution decreases, somehow “at the cost” of electron-like peak $E_1$, which becomes dominant at $T = 80$ K.

We believe that $E_1$ peak, detected at low temperatures, is associated with the presence of a surface inversion layer, observed on p-type InAs samples since 1970s. Later, the direct evidence for the existence of charge accumulation on free and clean InAs surfaces were reported, independently on type and doping level. Currently, it is widely believed that InAs has naturally high concentration of surface electrons, which might be, e.g., the main source of anomalous effects in temperature behavior of Seebeck coefficient. For example, Olsson et al. estimated electron surface concentration on about $10^{12}$ cm$^{-2}$, which compares well with our estimation of $n_{s0,1} = 3 \times 10^{12}$ cm$^{-2}$, at the lowest temperatures. Similar results have been obtained at $T = 300$ K by Lin et al. by QMSA method for the surface electrons on n-type sample, which also supports our identification of $E_1$ peak, the same as the fact that frequently published bulk electron mobilities are essentially higher. For high-quality samples $\mu_e > 1 \times 10^5$ cm$^2$ (V s)$^{-1}$ at 77 K. It is unlikely, however, that
the surface electron concentration reaches the extremely high value of $6.55 \times 10^{13} \text{ cm}^{-2}$, at $T = 80 \text{ K}$, as can be observed in Figure 4b. Therefore, the unexpected behavior of $E_1$ peak at the temperature Sets II and III might be an artifact of QMSA method, as we showed by the model calculations, described later.

Clearly, such artifacts related to electrons may also affect the identification of a hole-like mobility spectra. Fortunately, it is not the case for $T < 30 \text{ K}$ and $T > 200 \text{ K}$; therefore, in the following, we concentrate on the results obtained at low (Set I) and high (Set IV) temperatures. Judging from the partial concentrations and mobilities, $H_1$ spectrum is associated with heavy holes, whereas $H_2$ peaks originate from the presence of light holes, in agreement with the recent results of Casias et al.$^{[34]}$ for very similar $2 \mu\text{m}$-thick InAs$_{0.91}$Sb$_{0.09}$ layer, acceptor doped at $3 \times 10^{18} \text{ cm}^{-3}$ obtained at $T = 300 \text{ K}$. However, it is not clear what is the origin of the strong splitting of heavy-hole spectra, observed at low temperatures, which gradually disappears when peaks broaden and start to overlap.

To answer this question, we first assumed that the presence of the additional $H_1$ peak is not related to the inhomogeneity of our sample. This risk can lead to a wrong number of carriers species obtained by the MSA, as it was shown for two-carrier transport in a Hall-bar device.$^{[35]}$ However, the SIMS results (Figure 1a) show the excellent uniformity of both parent atoms and Be-dopant. Moreover, we believe that the application of vdP method effectively averages any residual inhomogeneities of our sample.

Second, we considered the anisotropy (so-called warping) of VB, which is characteristic for all $A^{III}B^V$ materials, as a possible source of peak splitting. We calculated the effective mass tensor for heavy holes using the InAs parameters and results showed that $\sigma_{xx}$ indeed deviates from the Drude formula. If a spherical Fermi surface and degenerate statistics are assumed, warping leads only to a broadening of mobility spectrum. In reality, Fermi momentum $k_F$ depends on crystallographic directions, so the noncircular shape of cyclotron orbits should be considered in a more detailed calculation. Also, in that case, however, no splitting but rather electron-like contribution is expected.$^{[36,37]}$

Therefore, we assumed that the additional $H_1$ peak is not related to inhomogeneities, QMSA artifact, or warping, but to an additional conduction channel in the degenerate VB, as explained later.

Degenerate statistics is suggested by a very weak temperature dependence of partial conductivities, observed up to $T \approx 10 \text{ K}$, which is characteristic for metallic transport. For higher temperatures, the $H_1$ contribution increases, which may suggest hopping-like conduction, which is rather typical for an amorphous films.$^{[38]}$ In our case, the $H_1$ conductivity does not follow Mott or Efros–Shklovskii laws$^{[39]}$ and the total contribution $H_1 + H_1'$ is practically temperature independent up to $30 \text{ K}$ (region I). The above conclusions led us to propose an alternative explanation of the splitting. We infer that such effect is a result of strained InAs interlayer presence between GaAs substrate and fully relaxed InAs layer. This assumption has been verified via numerical calculations performed in the nextnano software.$^{[40]}$

The assumptions about geometry do not differ much from Figure 1b, except additional $20 \text{ nm}$ surface cap layer and $200 \text{ nm}$ strained interlayer. The details have been shown in Figure 5. Beginning from the top part, we have $20 \text{ nm}$ surface states that correspond to $E_1$ channel. Unfortunately, proper modeling of the surface effects (especially for InAs) is a difficult challenge. To avoid this inconvenience, we proposed two numerical treatments. First, we use higher than “standard” effective density-of-states electron mass ($m^*_e \text{,dos} = 0.25 m_0$), which corresponds

![Figure 5. a) Assumed geometrical model of InAs layer on GaAs substrate, b) with calculated band-structure depth profile. Presented example is for 20 K (left side). The Fermi-level position calculated from the InAs midpoint crossing the top of the heavy-hole band above 100 K (right side).](image-url)
in our model to electron state from asymmetric near-surface quantum well. Second, we added two extra donor states to obtain the effect of electron concentration increasing above 30 K. Their concentrations have been $n_d = 3.0 \times 10^{19} \text{cm}^{-3}$ and $n_d = 5.0 \times 10^{18} \text{cm}^{-3}$, with activation energies $E_{D1} = -15 \text{meV}$ and $E_{D2} = -5 \text{meV}$, respectively. Numerical procedures for obtaining desired near surface concentration, such as increasing the $m_{\text{eff}}$ value, are rather typical treatment. In this case, however, more detailed calculations would be needed.

Due to the expected strain effects, we divided InAs layer (except surface) into two regions. We assumed that the first 1780 nm layer is practically relaxed, with $\varepsilon_{xx} = \varepsilon_{yy} = -0.8 \times 10^{-3}$ and $\varepsilon_{zz} = \varepsilon_{xy} = 0.9 \times 10^{-3}$. It is similar to averaged XRD and Raman measurement results (from this growth) published earlier, in which the parallel and perpendicular residual strain have been determined to be $-1.17 \times 10^{-3}$ and $1.12 \times 10^{-3}$, respectively.\[18\] The second 200 nm layer, close to the GaAs interface, has been assumed as relatively heavy stained with the parallel and perpendicular residual strain equal to $\varepsilon_{xx} = \varepsilon_{yy} = -0.0181$ and $\varepsilon_{zz} = \varepsilon_{xy} = 0.0197$, respectively. For both layers, the concentration of Be acceptors was $n_a = 3.2 \times 10^{18} \text{cm}^{-3}$, with different acceptor ionization energies equal to $E_A = -14 \text{meV}$ in the first layer and $E_A = -8 \text{meV}$ in the second one, counted from the top of the heavy-hole band. The effective density-of-states mass of electrons and all VBs, that is, heavy-hole ($m^*_{\text{hh,DOS}}$), light-hole ($m^*_{\text{lh,DOS}}$), and split-off band ($m^*_{\text{so,DOS}}$), have been used the same as suggested in the literature, namely 0.026, 0.41, 0.026, and 0.14 $m_e$, respectively.\[17\] It should be noted that the model did not require any special assumptions about the InAs/GaAs interface. GaAs “epi-ready” substrate before InAs deposition has been capped by the 0.25 $\mu$m GaAs layer, which effectively covered leftovers of impurities. Thus, we did not expect additional highly conductive interlayer.

In Figure 5b, the most interesting parts are placed between 500 and 700 nm and close to the surface region. For the first area, VB splitting on over 100 meV can be observed. In our opinion, despite relatively low thickness, this layer is the most probably source of the mobility spectra splitting (Figure 3a). We interpret it as the result of spatial change of shear strain in the InAs layer.

This type of strain causes splitting of heavy- and light-hole bands (see, e.g., ref. [41]), which can be observed in the strained 200 nm-thick interlayer, as in our case. Such splitting is sometimes intentionally used to suppress the Auger phenomenon in strained-layer superlattices.\[42\] This effect makes that the light-hole band moves down in the energy scale, away from the Fermi level. Therefore, we cannot observe light holes from that interlayer and for the same reason we cannot observe electrons from the bulk part of the InAs layer. Thus, we rejected here the intrinsic sheet concentration of electrons, as a reliable explanation of the origin of the $E_f$, because even for 300 K, this channel is negligibly small ($\approx 1 \times 10^6 \text{cm}^{-2}$). We conclude that conducting electrons come exclusively from the surface of our sample.

Moreover, we performed qualitative verification of calculations correctness. Namely, the relative Fermi-level position in the middle of unstrained InAs layer versus temperature has been checked to confirm occurring of the metal–semiconductor transition (right side of the Figure 5). The plot crosses the zero value, which means the Fermi level crossing the top of the heavy-hole band. This process takes place not exactly for 55 K, as in QMSA results, but for about 105 K. Presented results qualitatively confirm our interpretation related to Set II in Figure 4a,b. It is clear that the rapid changes of concentration and mobility are related to metal–semiconductor transition of InAs layer. To obtain the quantitative agreement, a more detailed fitting procedure would be necessary.

It is worth noting that negative ionization energies for acceptors have been used intentionally to simulate metallic conduction. Namely, $E_A = -14 \text{meV}$ in the first layer and $E_A = -8 \text{meV}$ in the second one, counted from the top of the heavy-hole band. These values are different from the literature data of $E_A \approx 20 \text{meV}$\[34\]. However, it is well known that as the dopant concentration increases, the dopants start to interact and form an impurity band.\[43–45\] The increase in the width of this band decreases the ionization energy.\[43–46\] For sufficiently high-dopant concentration, the associated broad impurity band and the conduction (valence) band edge merge leading to the negative ionization energies.

In the final step, the comparison between presented nextnano simulation and HR-QMSA analysis has been performed. The results are shown in Figure 6a,b. Except transitional regime

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**Figure 6.** Comparison of nextnano calculation results (solid lines and dashed line for heavy hole counted for 200 nm InAs interlayer) with sheet densities obtained by Hall measurements and HR-QMSA analysis (colored dots with the same description as in Figure 4a). a) Normalization to the assumed layer thicknesses and changing units in cubic centimeters show that volume concentration of both relaxed 1.8 $\mu$m and strained 0.2 $\mu$m are nearly the same.
and the results for channel $H_1^{\prime}$. Figure 6a shows a good agreement between two methods. However, the obtained numerical curves have no additional peaks for $30 \text{ K} < T < 110 \text{ K}$ and they behave smoother than the experimental ones. In our opinion, this comparison also suggests that unexpected appearance of $E_1$ peak might be an artifact of QMSA method.

In Figure 6a, normalization to the depth profile has not been applied. It has been made in the next step, in which normalization to the assumed layers’ thicknesses and changing units into cubic centimeters show that volume concentration of both 1.8 $\mu$m relaxed and 0.2 $\mu$m strained are nearly the same in the Boltzmann statistics regime. We infer here that the same volume concentrations might be the reason of disappearing of $H_1^{\prime}$ as a separate channel for $T > 55 \text{ K}$.

It should be noted that Hall effect measurements for any configuration similar to that presented in Figure 1b has fundamental limitation—it has 2D character. Therefore, rescaling procedure of carrier concentration from 2D to 3D system is rather arbitrary. During nextnano calculation, we noted that rescaling $H_1^{\prime}$ channel, assuming a thickness of 200 nm, gives the volume concentration for $T > 55 \text{ K}$ nearly the same value as $H_1$ for the rest of InAs layer. Therefore, channels $H_1$ and $H_1^{\prime}$ are indistinguishable via magnetotransport measurements above the temperature of metal–semiconductor transition. In our opinion, this is the most plausible explanation of the observed heavy-hole band splitting via HR-QMSA method.

The set of arguments have been presented that observed splitting of the heavy-hole-band mobility spectra origin from the thin, strained InAs interlayer between GaAs substrate and fully relaxed InAs layer despite its very high quality confirmed via multiple characterization techniques. Apart from the heavy holes, we also identified two additional channels: one related to surface-originated electrons and second one to light holes in the whole temperature range of 5–300 K. These results confirm the usefulness of the HR-QMSA technique even for the degenerate statistic regime. This interpretation has been supported by the comparison of experimental data with the numerical simulations performed for different temperatures, using the nextnano code.

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**Conflict of Interest**

The authors declare no conflict of interest.

**Author Contributions**

J.W. has made article concept, VMF measurements, final interpretation, and 1st version of the manuscript; G.U.-M. has made mobility spectra calculations; J.B. processed the high-quality Hall samples and supported writing of the manuscript; D.S. has made nextnano simulations; P.P.M. has made SIMS measurements and its interpretation; and J.W. supported interpretation part and proposed the final form of the manuscript. Finally, L.F., P.M., and A.R. assured internal review.

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