Chapter 2
On Few Electronic Properties of Nanowires of Heavily Doped Biosensing Materials

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Abstract **In this chapter, we study the** effective electron mass (EEM), the **Einstein relation for the diffusivity–mobility ratio (ER)**, **the Einstein's photoemission (EP)**, the field emission (FE) **and** the thermo-electric power (TP) in **heavily doped nanowires (HDNWs) of** different **biosensing materials** together with the relative comparison of the said transport features with that of the HDNW compounds. The EEM is an important transport quantity which is used in the analysis of different devices of low-dimensional electronics. The ER is useful in the characterizations of various types of hetero-structures and occupies a central position in the field of materials science. The EP is a physical phenomenon which finds extensive application in modern opto-electronics, and the FE is a quantum mechanical process. Besides, with the advent of quantum Hall effect, there has been considerable interest in studying the TP for various low-dimensional compounds. Although biosensing materials find wide applications and many physical properties have already been studied, nevertheless the investigations of the said electronic quantities for nanowires (NWs) of heavily doped (HD) biosensing materials are becoming increasingly important. Keeping this in mind in this chapter, an attempt is made to study the aforesaid quantities, **talking HDNWs of** various **biosensing material**s. We observe that the EEM is quantum number dependent. T**he ER oscillates with** the electron statistics (n_0) and t**he magnitude and nature of oscillations are totally different as compared with the ER in**

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HDNWs of other materials talking HDNW of InSb as an example. The Einstein's photo current from HDNWs of different biosensing materials **also oscillates with n_0 in radically different fashion as found from HDNWs of other materials. The field emitted current oscillates with increase in electric field due to van Hove singularities and the TP increases with increasing n_0 in oscillatory ways. The most important realization is that the quantum signatures in all the cases are not only totally different, but also the variations of the said electronic quantities as compared with that of HDNWs different compounds excluding biomaterials are also different**.

2.1 Introduction

The EEM [1–4], ER [5–8], EP [9–12], FE [13–16] and TP [17–20] have extensively been investigated in the recent literature, and they have important contributions in controlling control the transport phenomena in biosensing materials. Although biosensing materials find wide applications and many physical properties have already been studied [21–37], nevertheless it appears from the literature that the study of the said electronic properties has yet to be made. In this chapter, they are being investigated in HDNWs of biosensing materials. It may be noted that HDNWs are also being studied by various workers [38–40]. The theoretical background is described in Sects. 2.2, and 2.3 contains the results and discussion in this context.

2.2 Theoretical Background

The $E - k_x$ relation assumes the form [37]

$$k_x^2 = A_{11}(E, \eta_g, n_y) \tag{2.1}$$

where

$$A_{11}(E, \eta_g, n_y) = \left[\frac{2}{\sqrt{3}}\cos^{-1}\left[\left[[f\gamma(E,\eta_g)+g]^2 - 3 - D - 2\cos\left(\frac{n_y\pi}{d_y}\right)\right]\Big/\left(4\cos\left(\frac{3\pi n_y}{2d_y}\right)\right)\right]\right]^2$$

and the other notations are defined in [37]

The use of (2.1) leads to the expression of EEM as

$$m^*(E_F, \eta_g, n_y) = \frac{\hbar^2}{2}A'_{11}(E_F, \eta_g, n_y) \tag{2.2}$$

where the notations have their usual significances.

The n_0 can be written as

$$n_y = \frac{2g_v}{\pi} \sum_{n_y=1}^{n_{y\max}} \left[\sqrt{A_{11}(E_F, \eta_g, n_y)} + \sum_{r=1}^{r=n} 2(1 - 2^{1-2r})\xi(2r) \frac{\partial^{2r}}{\partial E_F^{2r}} \left[\sqrt{A_{11}(E_F, \eta_g, n_y)} \right] \right] \tag{2.3}$$

where the notations have their usual significances.

The ER can be expressed as

$$\frac{D}{\mu} = \left(\frac{n_0}{e}\right) \left[\frac{\partial n_0}{\partial (E_F - Z)} \right]^{-1} \tag{2.4}$$

where Z is given by

$$A_{11}(Z, \eta_g, n_y) = 0 \tag{2.5}$$

Thus by using (2.2)–(2.4), we can study the DMR numerically.

Incidentally, the photo current I can be written as

$$I = \frac{\alpha_0 e g_v k_{\mathrm{B}} T}{\pi \hbar} \sum_{n_y=1}^{n_{y\max}} \ln(1 + \exp[(E_F - (Z + W - h\upsilon))(k_{\mathrm{B}} T)^{-1}] \tag{2.6}$$

where α_0 is the probability of photoemission

The field emitted current (i_{f}) assumes the form

$$I = \frac{2 e g_v k_B T}{h} \sum_{n_y=1}^{n_{y\max}} [\ln(1 + \exp[(E_F - Z)(k_{\mathrm{B}} T)^{-1}] \exp(-Q)] \tag{2.7}$$

where

$$Q = \frac{4[A_{11}(V_0, \eta_g, n_y)]^{3/2}}{3eF_x \left[A'_{11}(V_0, \eta_g, n_y)\right]}, \quad V_0 = E_F + \phi_w$$

2.3 Results and Discussion

The plot of the normalized EEM in HDNWs of MOS_2 versus n_0 for three sub-bands is given in Fig. 2.1. The plots of normalized DMR ($\overline{D}$) in HDNWs of MOS_2 versus

n_0 are given in Figs. 2.2, and 2.3 shows the same for HDNWs of InSb for the purpose of relative comparison. Figures 2.4 and 2.5 explore the normalized photo current ($\overline{I}$) from HDNWs of MOS_2 versus n_0 and the same for HDNWs of InSb respectively. Figures 2.6 and 2.7 exhibit the plots of the normalized FE and TP for different HDNW biomaterials versus n_0 respectively.

The salient features are given below:

1. In Fig. 2.1, the EEM increases with increasing n_0 where the value of EEM for $n_y = 1$ is the greatest.
2. In Fig. 2.2, the $\overline{D}$ in HDNWs of MOS_2 oscillates with enhanced n_0, and the magnitude and nature of oscillations are totally different as compared with the $\overline{D}$

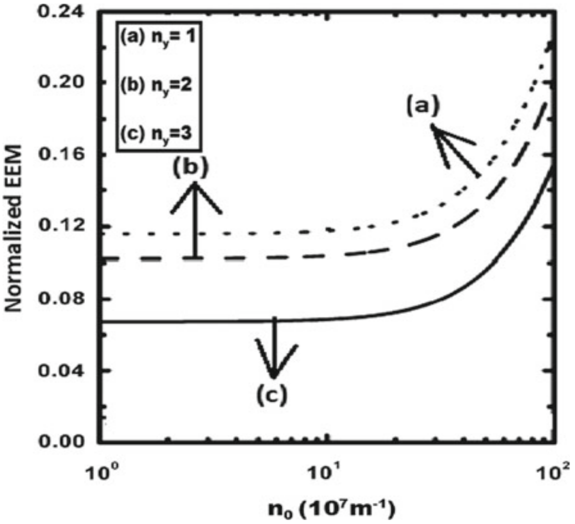


Fig. 2.1 Plot of the normalized EEM versus n_0 for three different values of n_y in HDNW MOS_2 where $d_y = 20$ nm

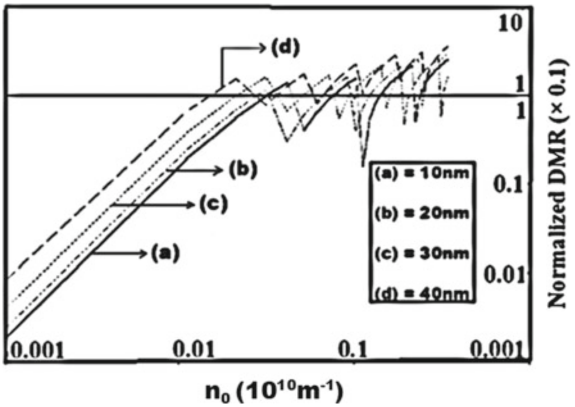


Fig. 2.2 Plot of the $\overline{D}$ in HDNWs of MOS_2 versus n_0 for four different values d_y as shown in the figure

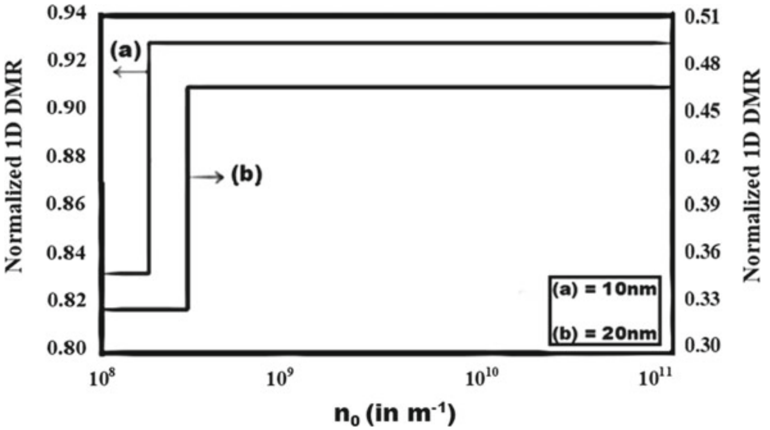


Fig. 2.3 Plot of the $\overline{D}$ versus n_0 for the NWs of $n-$InSb with two different values of d_y

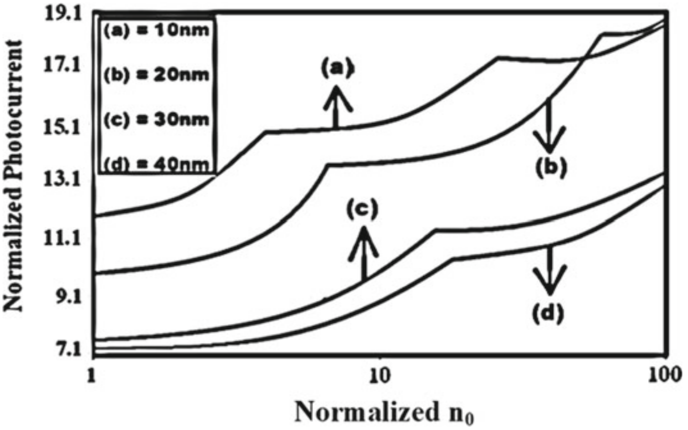
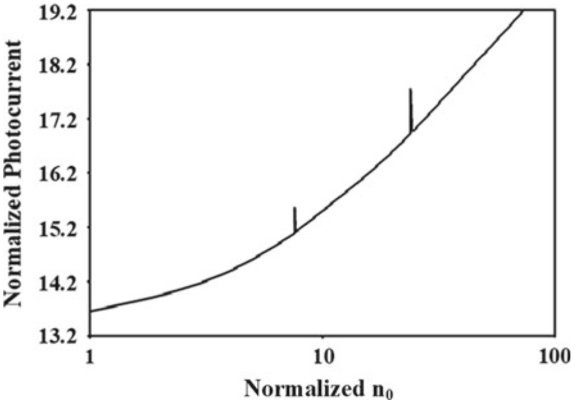


Fig. 2.4 Plot of the $\overline{I}$ from NWs of MOS_2 versus n_0 for four different values of film thickness

Fig. 2.5 Plot of the $\overline{I}$ versus n_0 for the NWs of $n-$InSb



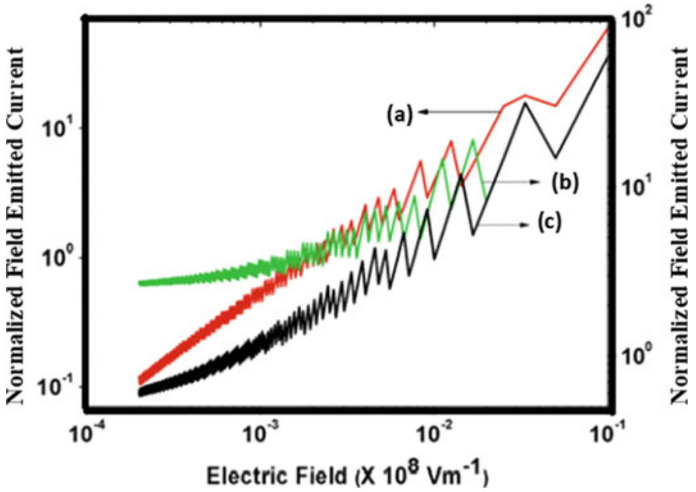


Fig. 2.6 Plot of the normalized field emitted current versus electric field for three different HDNWs of biomaterials

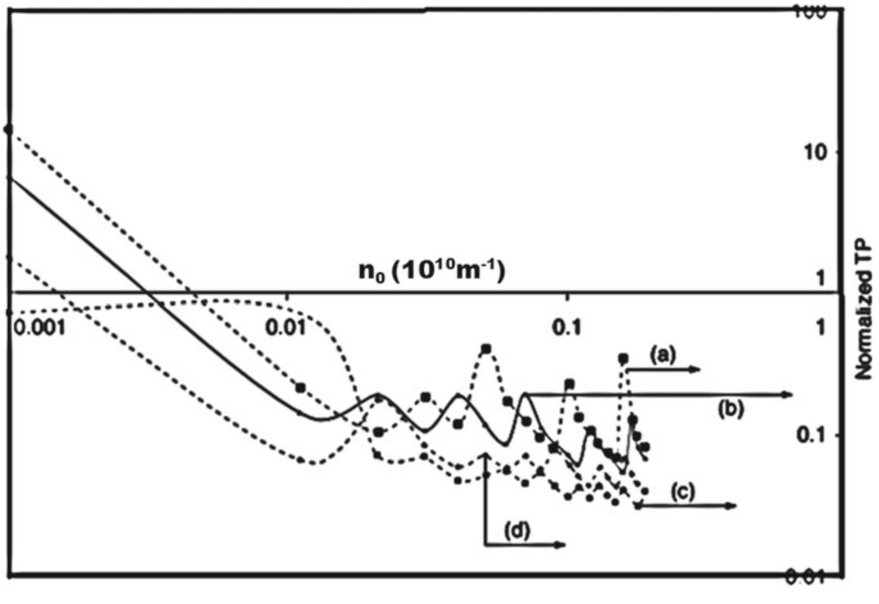


Fig. 2.7 Plot of the normalized TP versus n_0 for four different HDNWs of biomaterials as shown by a, b, c and d, respectively

in HDNWs of other material as given in Fig. 2.3. The quantum signatures of two different types of 1D motion can be assessed by comparing Figs. 2.2 and 2.3.

3. From Figs. 2.4 and 2.5, it appears that the $\overline{I}$ HDNWs of MOS_2 oscillates with n_0 in radically different manner as compared with that from HDNWs of other materials.
4. From Fig. 2.6, we note that the field emitted current oscillates with increase in electric field due to Van Hove singularities
5. From Fig. 2.7, we note that the TP increases with increasing n_0 in oscillatory ways.

Most important to realize is that the quantum signatures in all the cases are not only totally different, but also the variations of the said electronic quantities as compared with that of HDNWs different materials excluding biocompounds are also different.

2.4 Conclusion

In this chapter, we study the EEM, **ER, EP**, FE **and** the TP in **heavily doped nanowires (HDNWs) of** different **biosensing materials** together with the relative comparison of the said transport features with that of the HDNW compounds. We observe that the EEM is quantum number dependent. T**he ER oscillates with** the electron statistics (n_0), and t**he magnitude and nature of oscillations are totally different as compared with the ER in HDNWs of other materials talking HDNW of InSb as an example. The Einstein's photo current from HDNWs of** different biosensing materials **also oscillates with n_0 in radically different fashion as found from HDNWs of other materials.** The field emitted current oscillates with increase in electric field due to Van Hove singularities, and the TP increases with increasing n_0 in oscillatory ways. **The most important realization is that the quantum signatures in all the cases are not only totally different, but also the variations of the said electronic quantities as compared with that of HDNWs different compounds excluding biomaterials are also different.**

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