Erratum: Spin injection into silicon in three-terminal vertical and four-terminal lateral devices with Fe/Mg/MgO/Si tunnel junctions having an ultrathin Mg insertion layer **[Phys. Rev. B 96, 235204 (2017)]**

Shoichi Sato, Ryosho Nakane, Takato Hada, and Masaaki Tanaka

(Received 14 April 2018; published 17 May 2018)

DOI: [10.1103/PhysRevB.97.199901](https://doi.org/10.1103/PhysRevB.97.199901)

In the Supplemental Material (SM) [34] of our original paper, we derived Eq. (S30) for the narrower three-terminal Hanle (N-3TH) signal, taking into account the depletion region in Si, and explained the absence of the N-3TH signal in the spin injection regime. This N-3TH signal equation was derived by solving the one-dimensional (1D) spin drift-diffusion equation Eq. (S27) under the approximated electric-field distribution Eq. (S26). However, the boundary conditions in Eqs. (S28a)–(S28c) were erroneously introduced, and the drift term by the electric field was missing. The corrected boundary conditions are as follows:

$$-D \frac{d}{dz} \hat{S}(z) + \mu E(z) \hat{S}(z) \Big|_{z=0} = \frac{P^I J}{q}, \quad (\text{S28a})$$

$$-D \frac{d}{dz} \hat{S}(z) + \mu E(z) \hat{S}(z) \Big|_{z=L_D-0} = -D \frac{d}{dz} \hat{S}(z) \Big|_{z=L_D+0}, \quad (\text{S28b})$$

$$\hat{S}(z) \Big|_{z=L_D-0} = \hat{S}(z) \Big|_{z=L_D+0}, \quad (\text{S28c})$$

$$\hat{S}(z) \Big|_{z<0} = 0, \quad (\text{S28d})$$

$$\hat{S}(z) \Big|_{z \rightarrow \infty} = 0. \quad (\text{S28e})$$

Using them, the solution of Eq. (S27) is as follows:

$$\hat{S}(z) = \begin{cases} \frac{S_0}{X} [(\alpha - \beta^-) \exp(\beta^+ L_D) \exp(\beta^- z) - (\alpha - \beta^+) \exp(\beta^- L_D) \exp(\beta^+ z)] u(z) & (0 \leq z \leq L_D) \\ \frac{S_0}{X} (\beta^+ - \beta^-) \exp[(\beta^+ + \beta^-) L_D] \exp[-\alpha(z - L_D)] u(z) & (L_D \leq z), \end{cases} \quad (\text{S29})$$

where $S_0 = \frac{P^I J}{qD}$, $\alpha = \frac{\sqrt{1+i\gamma H \tau_S}}{\lambda_S}$, $\beta^\pm = \frac{\mu E_S \tau_S / 2 \lambda_S \pm \sqrt{(\mu E_S \tau_S / 2 \lambda_S)^2 + 1 + i\gamma H \tau_S}}{\lambda_S}$, and

$$X = \alpha [(\alpha + \beta^+) \exp(\beta^+ L_D) + (\alpha + \beta^-) \exp(\beta^- L_D)].$$

Thus, the corrected N-3TH signal equation is as follows:

$$\Delta V^{\text{N-3TH}}(H, E_S) = V_0^{\text{spin}} \text{Re} \left[\frac{1}{\alpha} \frac{(\alpha - \beta^-) \exp(\beta^+ L_D) - (\alpha - \beta^+) \exp(\beta^- L_D)}{(\alpha + \beta^+) \exp(\beta^+ L_D) + (\alpha + \beta^-) \exp(\beta^- L_D)} \right]. \quad (\text{S30})$$

Based on these corrections in Eqs. (S28)–(S30), we correct Fig. S5 (as shown on the next page), which presents the bias dependence of the amplitude and linewidth of the N-3TH signal. Whereas the amplitude is proportional to V_0 at $V_0 < 0$ V and almost zero at $V_0 > 0$ V [Fig. S5(a)], the linewidth is almost constant [Fig. S5(b)]. Although Eq. (S30) is corrected, the main conclusion remains unchanged; the absence of the N-3TH signal in the spin injection regime can be explained by the depletion region in Si.

Due to the correction of Eq. (S30), some descriptions in the main paper and the Supplemental Material [34] are corrected as follows (the underlines are the corrected parts):

Section II C in the main paper (p. 4, lines 7–17):

...Using the 1D Poisson's equation, the maximum electric-field strength in the Si depletion layer in our sample was estimated to be 3.4 MV/cm when $I = +30$ mA, and this electric field decreases the amplitude of the N-3TH signal down to nearly zero (see the SM [34]). Thus, it is reasonable that no clear N-3TH signal appears in the spin injection regime because such a small N-3TH signal cannot be distinguished from the large B-3TH signals even if it exists.

Section S6 in the Supplemental Material (p. S-14, line 13 and p. S-15, line 4) [34]:

The amplitude of the N-3TH signals in the spin extraction regime ($V_0 < 0$) linearly increases with $|V_0|$. On the contrary, in the spin injection regime ($V_0 > 0$), the amplitude of the N-3TH signals decreases with increasing V_0 ; this is because the spin-polarized electrons in the depletion layer of the Si channel are drifted away from the interface by the electric

FIG. S5. Calculated (a) amplitude and (b) linewidth of the N-3TH signal using Eq. (S18) for the negative bias (the spin extraction regime) and Eq. (S30) for the positive bias (the spin injection regime). Experimental results of the vertical device with $t_{\text{MgO}} = 0.8$ and $t_{\text{Mg}} = 1.0$ nm are also plotted by the open circles in (a).

field. The linewidth of the N-3TH signal in the spin injection regime is constant and almost the same as that in the spin extraction regime.

-
- [34] See Supplemental Material at <http://link.aps.org/supplemental/10.1103/PhysRevB.96.235204> for (S1) derivation of the three-dimensional impulse response for the vertical device, (S2) derivation of the two-dimensional impulse response for the vertical device, (S3) derivation of the 2D impulse response for the lateral device, (S4) three-terminal Hanle signals in a vertical device structure, (S5) three-terminal and four-terminal Hanle signals in the lateral device, (S6) bias dependence of the N-3TH signals in degenerated semiconductors, and (S7) the reason for the absence of four-terminal Hanle signals in setup II.