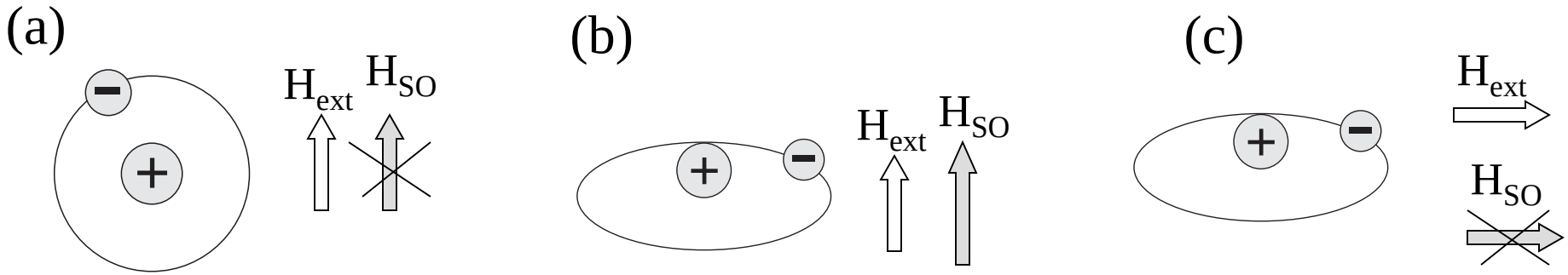

Fig.1. Prior Art. The dependence of the effective magnetic field of spin-orbit interaction H_{SO} on the degree of the orbital deformation and the deformation direction with respect to the applied external magnetic field H_{ext}. (a) $H_{SO}=0$ for spherical orbital. (b) $H_{SO}=0$ for deformed orbital when an external magnetic field H_{ext} is applied perpendicularly to the deformation. (c) $H_{SO}\neq 0$ for deformed orbital and external magnetic field H_{ext} is applied along the deformation. The absolute value of the electron magnetic energy is larger in the case (c) and smaller in the cases (a) and (b).

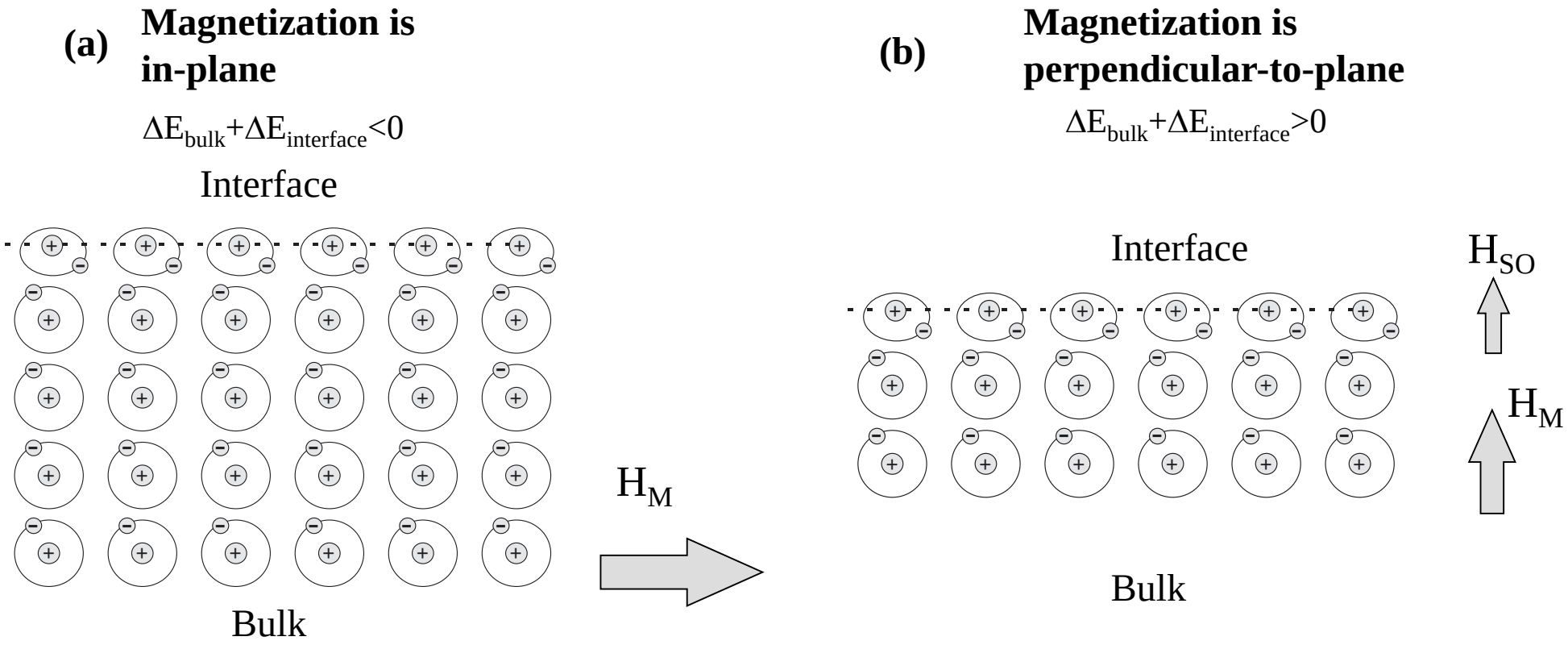

Fig.2. Prior art. Dependence of the magnetization of ferromagnetic thin film on the orbital deformation at the interface and the thickness of the film. The cross-section of a nanomagnet is shown as an array of its electronic orbitals. H_M shows the intrinsic magnetic field along the magnetization. The bulk orbitals are spherical and therefore bulk electrons do not experience H_{SO} for any direction of the magnetization. Their magnetic energy is smaller when magnetization is in-plane ($\Delta E_{bulk}<0$). The interface orbitals are deformed perpendicularly to the plane and therefore the interface electrons experience H_{SO} when magnetization perpendicular to plain. The contribution of H_{SO} makes $\Delta E_{interface}>0$. (a) A thicker film. There are more bulk electrons and $\Delta E_{bulk}+\Delta E_{interface}<0$. Therefore, the magnetization is in-plane. (a) A thicker film. There are less bulk electrons and $\Delta E_{bulk}+\Delta e_{interface}>0$. Therefore, the magnetization is perpendicular-to-plane.

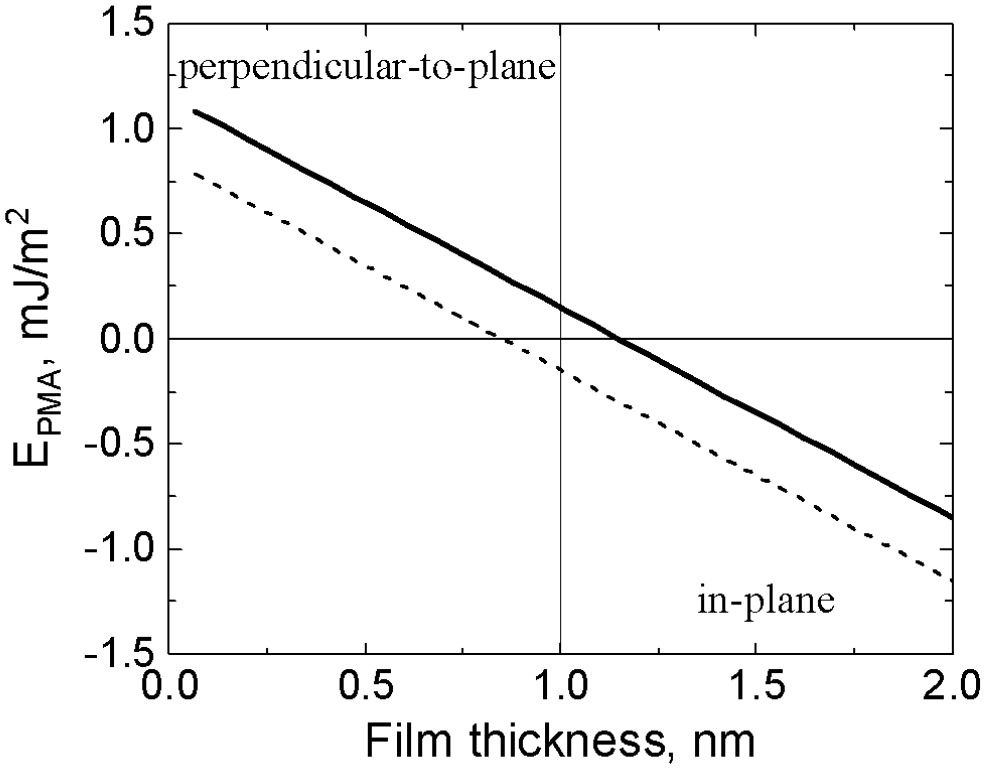

Figure 3. Prior Art. The energy of perpendicular magnetic anisotropy E_{PMA} of FeB thin film as a function of the film thickness. The negative energy means that magnetization is in-plane. Two cases of a different values of the orbital deformation at the interface with the interface energy of 1.15 mJ/m^2 (solid line) and 0.85 mJ/m^2 (dash line) are shown. In the case of film thickness of around 1 nm, the magnetization direction of the film can be changed from in-plane to perpendicular-to-plane direction by the variation of orbital deformation.

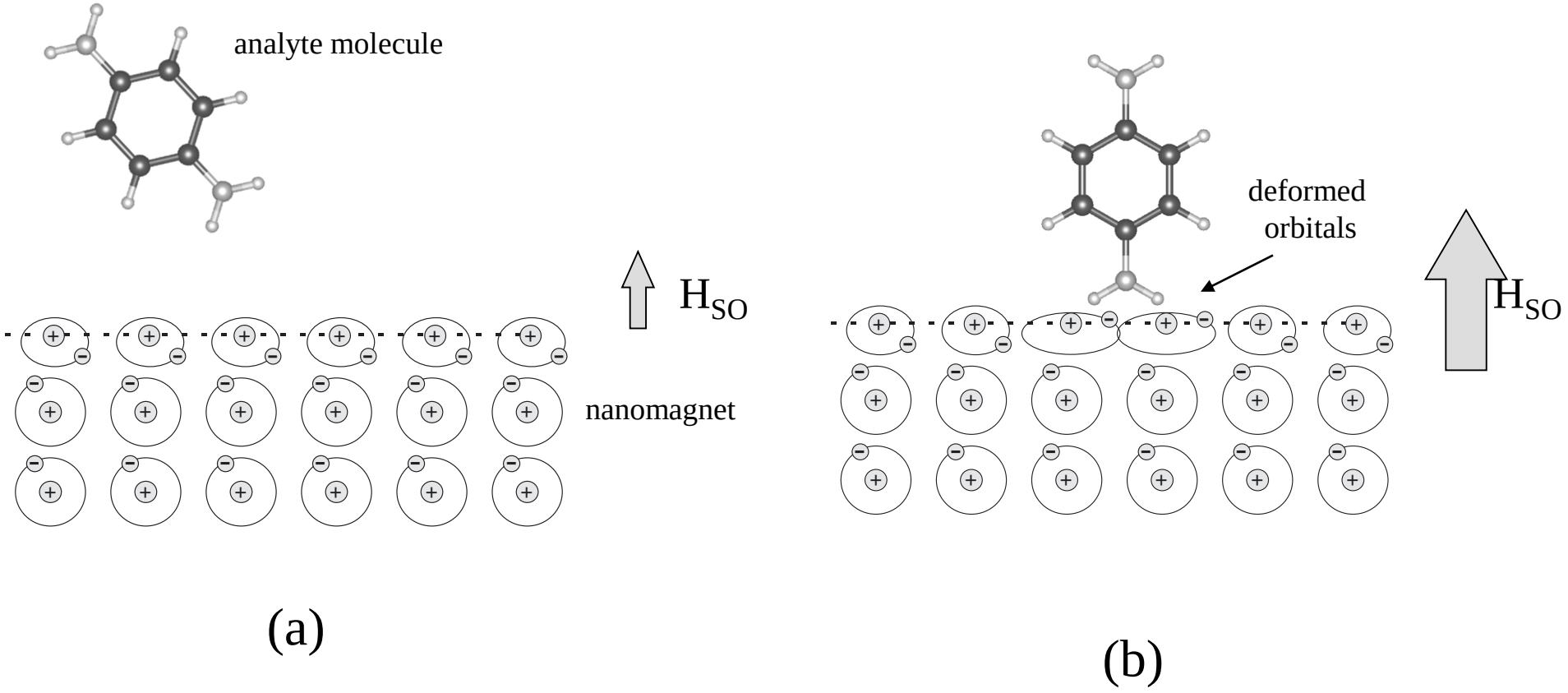

Figure 4. Detection method of the disclosed invention. The cross-section of a nanomagnet is shown as an array of its electronic orbitals. (a) The analyte molecules are far from the top interface of a nanomagnet. The electron orbitals on the top of the nanomagnet are not influenced by the analyte molecule. H_{SO} is small. The PMA energy E_{PMA} is small (b) The analyte molecule interacts with the interface of the ferromagnetic film and deforms its interface orbitals. As a result, the H_{SO} becomes larger and the PMA energy E_{PMA} increases.

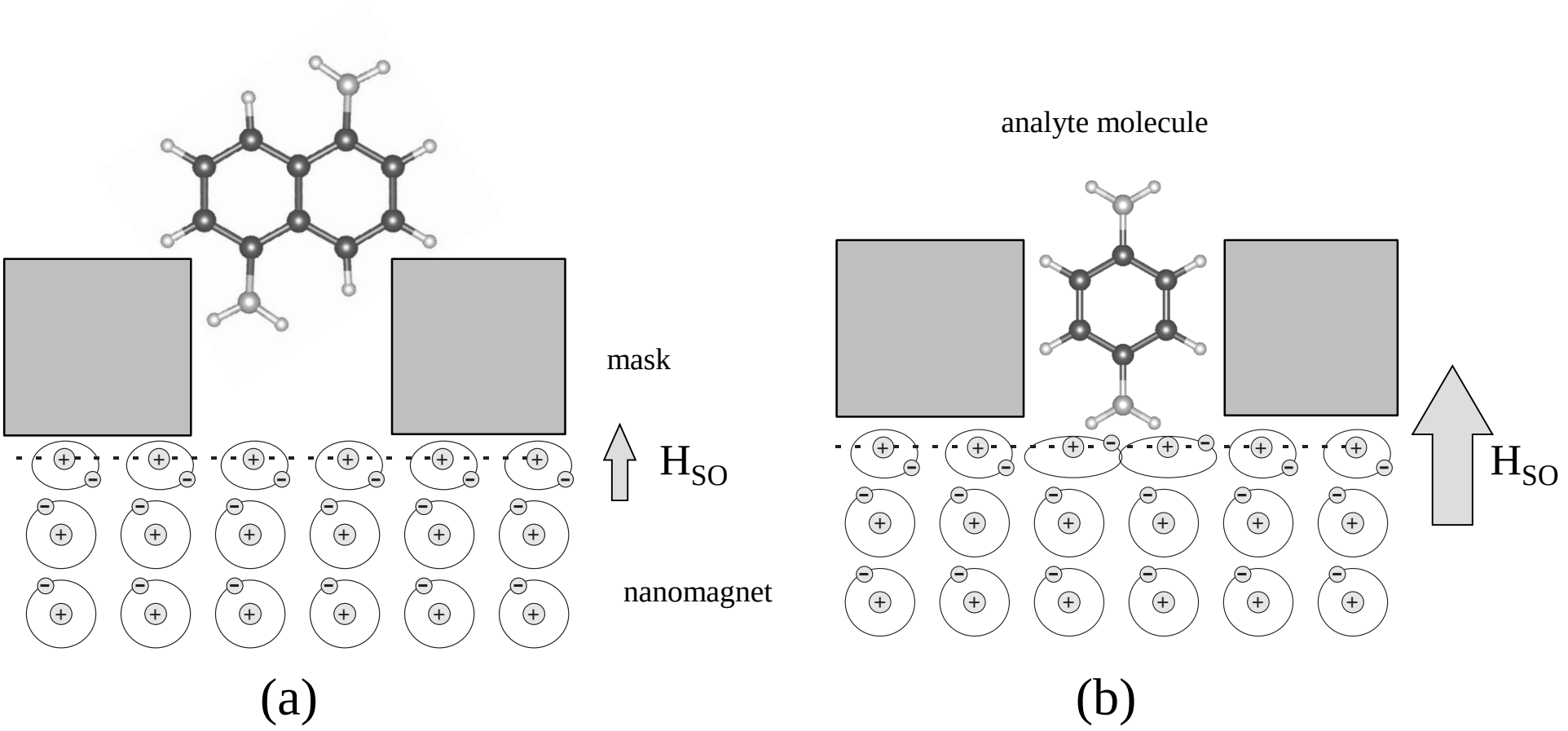

Figure 5. Molecular recognition method using a mask. The molecular mask of a non-magnetic material is deposited on the top of the ferromagnetic film. The composition of the molecular masks and size of the openings in the mask specifically match the shape, size and chemical nature of the analyte molecules. (a) The molecule does not match the openings of the mask. It cannot approach the interface of the film and cannot be detected. (b) The analyte molecule, which can pass through the mask, interact with the interface of the ferromagnetic film and deform its interface orbitals. As a result, the PMA energy E_{PMA} increases and the analyte molecule is detected.

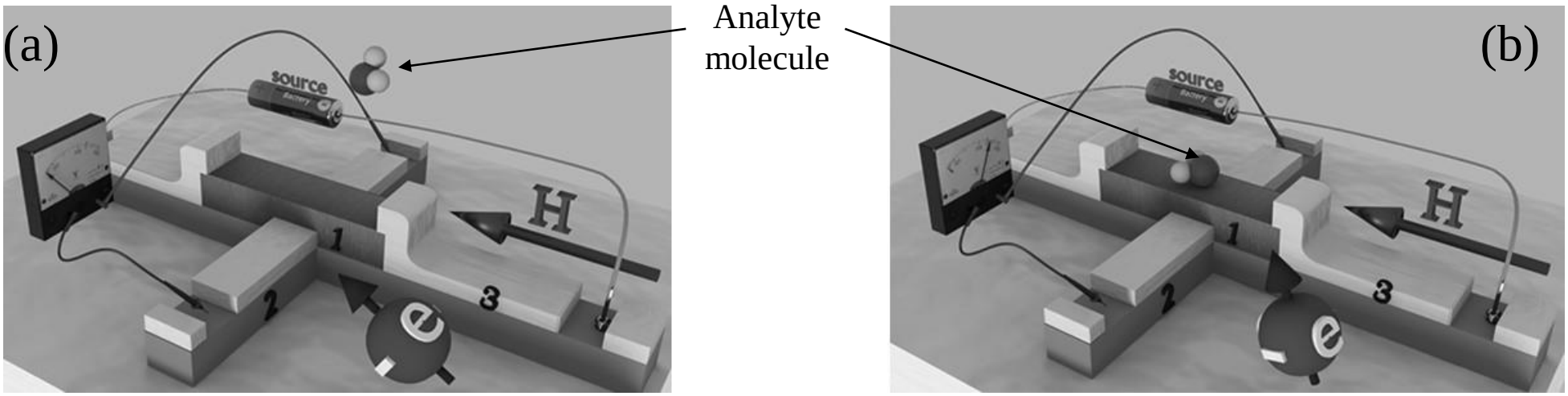

Figure 6. The Hall probe sensor consisting of a nanomagnet (1) on the top of a non-magnetic nanowire(2) with an isolation layer (3). A bias current flows through the nanowire. Two Hall probes are contacting the nanowire to detect the Hall voltage. External magnetic field H is applied in-plane of the nanowire. The ball with arrow shows the magnetization direction of the nanomagnet. (a) The tested molecule is far from the nanomagnet. The angle α of the magnetization with respect to in-plane direction is small. As a result, the Hall voltage is small. (b) The tested molecule is in proximity of the nanomagnet interface. An additional PMA is induced. As a result, the angle α increases, the Hall voltage becomes larger and the proximity of the molecule is detected.

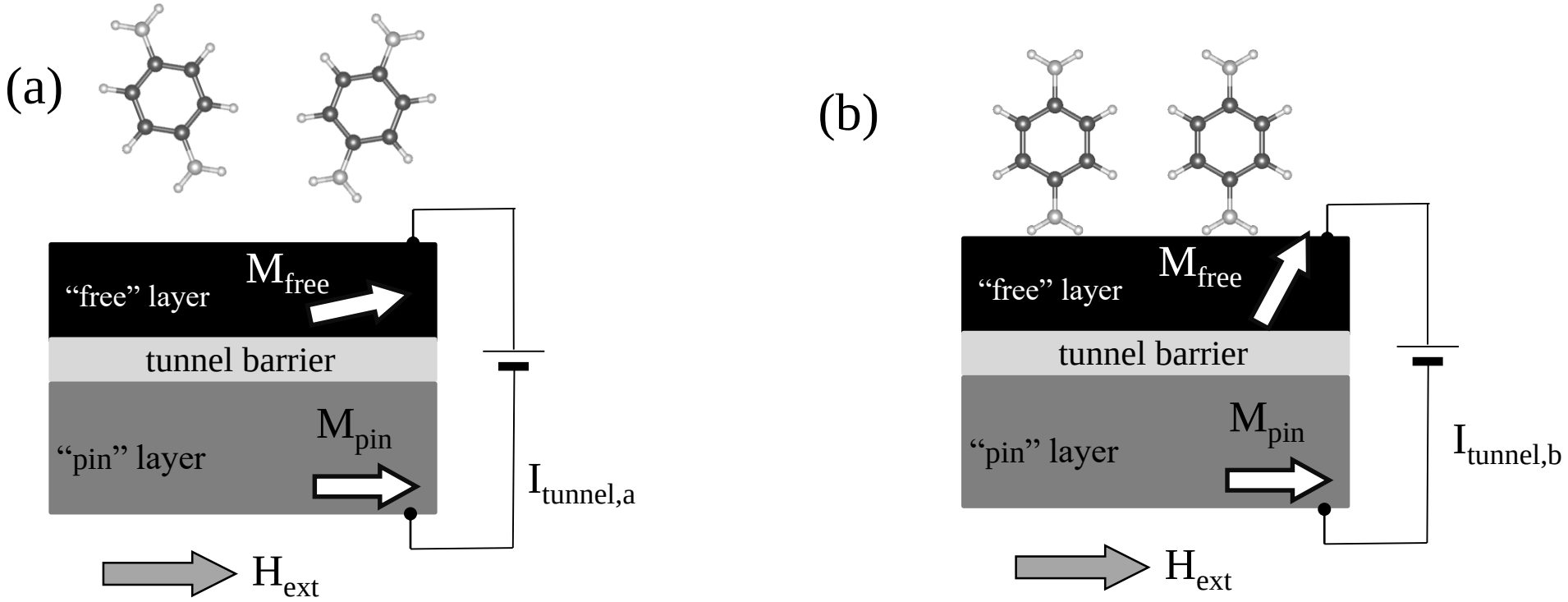

Figure 7. The MTJ sensor consists of a thicker "pin" electrode, which equilibrium magnetization is in-plane, a thinner "free" electrode, which equilibrium magnetization is perpendicular-to-plane, and a thin tunneling barrier layer between the "pin" and "free" layers. An external magnetic field H_{ext} is applied in-plane. It turns the magnetization M_{free} of "free" layer towards in-plane direction. The inclination angle α of M_{free} depends on the strength of PMA of "free" layer. A bias voltage is applied between the "pin" and "free" layers and a tunneling current flows between the layers. The tunneling current depends on the mutual angle a between magnetizations of the "pin" and "free" layers. (a) there is no analyte molecules in the proximity of the "free" layer. The PMA energy E_{PMA} is small. The M_{free} inclines more to in-plane direction and M_{pin} direction. As a result, $I_{tunnel,a}$ is larger. (b) The analyte molecules is near the top interface of "free" layer. The PMA energy E_{PMA} becomes stronger. The M_{free} inclines more to perpendicular-to-plane direction. The angle between M_{free} and M_{pin} direction becomes larger. As a result, the tunneling current becomes smaller $I_{tunnel,b} < I_{tunnel,a}$.