[0018] The spin tunnel transistor according to the first embodiment has a ferromagnetic metal layer 5, a non-magnetic metal layer 7, a ferromagnetic metal layer 9, a barrier layer 11, and a non-magnetic metal layer 13, which are stacked on a crystalline semiconductor layer (or substrate) 1 of silicon, etc. through an interface layer 3 formed on the semiconductor layer by epitaxial growth in order.

[0019] Here, the semiconductor layer 1 constitutes a collector of the spin tunnel transistor; the ferromagnetic metal layer 5, non-ferromagnetic metal layer 7 and ferromagnetic metal layer 9 constitute a base; and the non-magnetic metal layer 13 constitutes an emitter. In addition, the barrier layer 11 of a dielectric material is formed between the base and emitter, and a tunnel barrier is formed between the ferromagnetic metal layer 9 and the non-magnetic metal layer 13. Therefore, the spin tunnel transistor has a MIMS structure.

[0020] The ferromagnetic metal layer 5 of the base is a fixedly-magnetized layer with a fixed magnetization M1. The ferromagnetic metal layer 9 is a free-magnetized layer with its magnetization M2 variable according to application of an external magnetic field H (other than zero magnetic field). More specifically, the application of an external magnetic field H to the base in the direction from the left to the right in the sheet of **FIG. 1** turns the ferromagnetic metal layer **9** into the magnetization M2 in parallel with the magnetization M1; the application of an external magnetic field H' to the base in the direction from the right to the left in the sheet of **FIG. 1** turns the ferromagnetic metal layer 9 into the magnetization M2, in antiparallel with the magnetization M1. As for the fixedly-magnetized layer, the magnetization thereof may be moved somewhat when an external magnetic field H is applied. However, the change is small with respect to the movement of the magnetization of the free-magnetized layer and is on the level where the change cannot affect the change of MR of the spin tunnel transistor.

[0021] The amount of a current passing through the stacked film of the base is proportional to the cosine of a relative angle between the magnetizations M1 and M2. Therefore, the base resistance becomes minimum under the external magnetic field H and it becomes maximum under the external magnetic field H' (Magnetoresistive Effect). The change of MR depending on an external magnetic field can be sensed by measuring a current flowing through the spin tunnel transistor and a corresponding voltage value.

[0022] Incidentally, as for a so-called spin-valve type device, the ferromagnetic metal layer 9 is so set that its magnetization forms an angle of 90 degrees with respect to the fixed magnetization of the ferromagnetic metal layer 5 (or is turned to a direction perpendicular to a surface of the sheet of **FIG. 1**) in the condition where a zero magnetic field is applied. Further, in regard to a base of an antiferromagnetic coupled GMR device, the ferromagnetic metal layers 5, 9 are antiferromagnetically coupled with each other in the condition where a zero magnetic field is applied (when the magnetoresistance is made maximum); under the influence of a given magnetic field, the antiferromagnetic coupling is cut and thus the magnetization is aligned in the same direction as that of the applied magnetic field (and the magnetoresistance is made minimum).

[0023] The change of MR is measured by determining a collector current. On this account, the collector is connected to an external circuit through an electrode (i.e. a collector terminal C) formed on, for example, a side surface of the semiconductor layer 1 or the rear surface opposite to the surface adjacent to the interface layer 3.

[0024] Further, in a spin tunnel transistor, the emitter and the base are also connected to an external circuit for the purpose of applying a voltage between the emitter and the base to inject electrons (i.e. hot electrons HE). More specifically, the base is connected to the external circuit through a base terminal B in its end portion; the emitter is connected to the external circuit through an emitter terminal E of the non-magnetic metal layer 13 or of other metal electrode layer or the like, which are connected to the non-magnetic metal layer 13.

[0025] **FIG. 2** is an energy diagram of the spin tunnel transistor shown in **FIG. 1**.

[0026] An emitter voltage is applied between the emitter and the base to inject hot electrons HE into the base from the emitter. The electrons (hot electrons HE) injected into the base from the emitter are scattered according to the respective spins in the base. Then some of the injected hot electrons HE (HE↑ in **FIG. 2**) pass across the Schottky barrier between the interface layer 3 and the semiconductor layer 1 and reach the collector.

[0027] The magnetoresistive effect ratio (MR ratio) of the spin tunnel transistor is a result of the non-equivalence of conductivities between electrons each having a spin magnetic moment in parallel with the magnetizations of the ferromagnetic metal layers 5, 9 (e.g. up-spin electrons HE↑) and electrons each having a spin magnetic moment in antiparallel with the magnetizations (e.g. down-spin electrons HE↓) in the magnetic stacked film of the base. The collector current produced by the hot electrons, which have passed over the Schottky barrier and reached the collector, flows out from the device through the terminal and then to be sensed.

[0028] Here, the main reason of a small current transmittance of the spin tunnel transistor seems to be that the hot electrons are subjected to strong reflections in the interface between the metal base and the semiconductor collector. The reflections are classified into the reflection caused by an interface barrier formed at the time of creating the Metal/Semiconductor layer interface and the quantum mechanical reflection caused by the difference in electron wavelength between the semiconductor layer and the metal layer. For the reflections, it has been found out that the reflection caused by the interface barrier is especially larger than the other and strongly depends on the material in the interface between the metal layer and the semiconductor layer.

[0029] First, the current transmittances for the base and the collector of a spin transistor can be expressed as the expression (1) approximately.

[Number 1]

$$\frac{I_C}{I_E} = T_{M\to S} \times \sum \left[T_{M\to M} \times \exp\left(-\frac{D}{\lambda}\right) \right] \tag{1}$$

[0030] In the expression, I_C is a collector current value; I_E represents an emitter current value; $T_{M\to S}$ is a current