

Two Terminal Switching Device for Spin Transfer Torque (STT) MRAM

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1. Introduction

During the last decade, new memories such as PRAM, RRAM, and MRAM have challenged conventional NVMs. In nowadays, spin-transfer-torque magneto-resistive RAM (STT-MRAM), that used tunnel magneto resistance (TMR) device and the direction of current to determine writing data, has emerged as a promising candidate for high density and scalable nonvolatile memory [1]. However, the scaling down of MOSFET such as a typical selective device in 1T-1MTJ array architecture under the sub-90nm is limited by short channel effect, which generates the leakage current [2]. Therefore, new array architecture has to be considered to eliminate the problem with both capability and reliability by selective transistor. The selective device normally consists of diode instead of MOSFET [3], but the diode cannot be adopted due to a bidirectional current flow for the write operation in STT-MRAM.

In this work, we proposed a N+/P/N+ Si junction device with symmetrical N+ doping as a bidirectional switching device in STT-MRAM, and it is investigated for better operation in two terminal switching device by simulation method. The P junction doping and length are the most critical parameter. As a P layer length decrease, a switching characteristic is significantly improved. However, since a longer P layer length is more feasible in mass production, we present one device condition about P and N+ regions with doping concentration and length for real application.

2. Simulation result and Discussion

Schematic of Bidirectional Switching Device

A schematic of proposed N+/P/N+ Si junction switching device which is corresponding for the sub-30 nm STT-MRAM is shown in Fig. 1(a). It consists of P junction and N+ regions with total length of 150 nm and area of $30 \times 30 \text{ nm}^2$ size. In fig. 1 (b), STT-MRAM with N+/P/N+ Si junction structure for a switching device is compared to the conventional. For STT-MRAM, a selective device must provide a bidirectional write operation with a sufficient current flow as well as high on/off ratio of over 10^6 for reliability [3]. The write current of sub-30 nm MTJ is required below $30 \text{ } \mu\text{A}$ [4]. This junction device is operated by a fully-depletion of P junction like a DIBL. For instance, if P doping concentration becomes high, it is hard to make a fully-depletion. Due to this reason, the P doping concentration must have lower than N doping concentration like the N+/P/N+. It is also possible to make a bidirectional current flow because of perfectly symmetric structure.

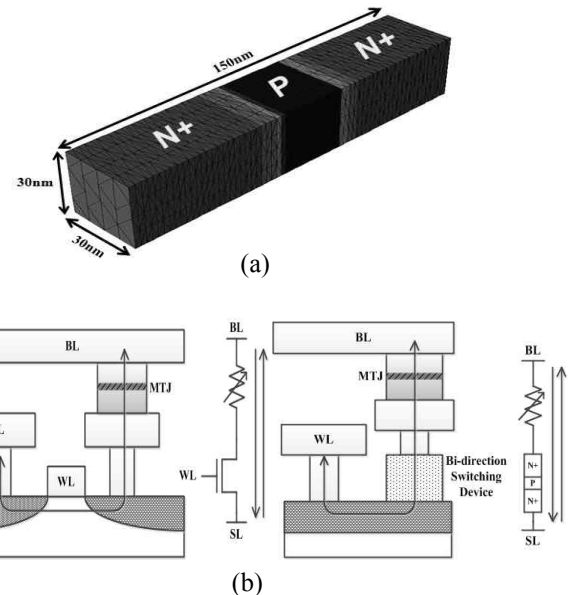


Fig. 1 (a) The schematic of proposed two terminal N+/P/N+ Si junction bidirectional switching device, (b) the comparison for the conventional 1T-1MTJ and the proposed 1D-1MTJ.

Simulation Discussion

A N+/P/N+ Si junction switching device has been developed and implemented in the Sentaurus Device tool, and it has been found out what optimized conditions are. In our previous research [5], we proposed Poly-Si junction structure for switching device in STT-MRAM. In this work, we simulated a junction device for more feasibility by split the various parameters: P doping concentration, N+ doping concentration, P length, N+ length, and P junction width. Fig. 2(a) shows simulation results that total length, length with P-region, and length with N+ region before doping are 150 nm, 70 nm, and 40 nm, respectively, and Fig. 2(b) shows that each length is exactly same with 50 nm. Actual P length is decided from a doping profile due to diffusion, which caused by difference between each doping concentration. From simulation results, we found the condition to satisfy enough high on/off ratio and drive current, and we confirm that P doping concentration and junction width are very important as a determining the switching characteristics, and N+ doping concentration is proportional to the amount of the drive current. For example, if P doping is too low under the $9 \times 10^{17} \text{ cm}^{-3}$ in Fig 2(a), P junction width will be more reduction due to difference between P and N+

doping concentrations, and this makes more easily depleted P junction and much more current. The on-off ratio is, however, almost near zero like a resistance. As shown in Fig. 2, the entire current density of Fig. 2(b) is higher than Fig. 2(a) because P-junction length of Fig. 2(b) is shorter than Fig. 2(a).

We choose the proper parameters, which are P doping with $1\sim 3 \times 10^{18} \text{ cm}^{-3}$ and N+ doping with $1 \times 10^{20} \text{ cm}^{-3}$. At this condition, the P junction length is about 30 nm that is more feasible length to fabricate than previous research [5].

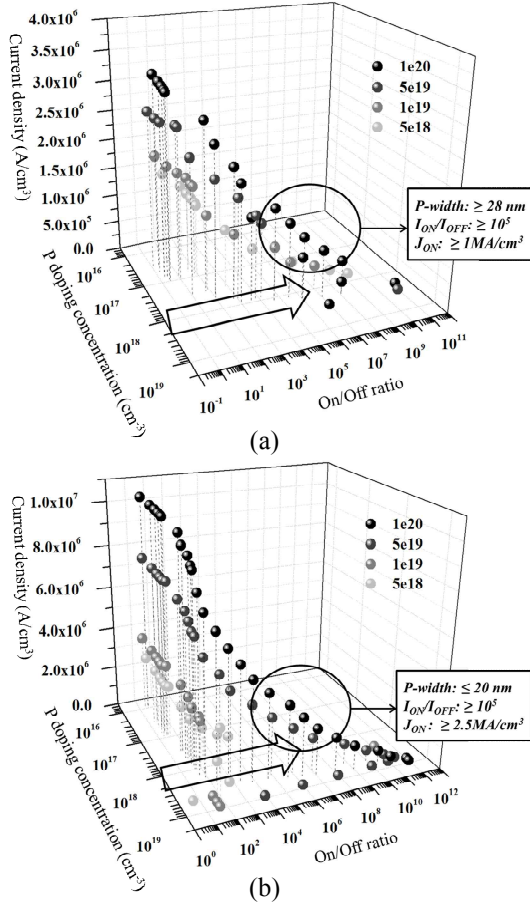


Fig. 2 Switching characteristics by split conditions with (a) 40/70/40 and (b) 50/50/50 before doping.

Optimization and Future Work

As shown in Fig. 3, we present the I-V characteristics in linear and logarithm scales to observe more details. As mentioned earlier, we already mentioned that junction device must not be reasonable feasibility, but also have enough drive current and high on/off ratio to change a magnetization for MTJ. The optimized condition of the two terminal N+/P/N+ Si junction bidirectional switching device in Fig. 2 (a) is P doping with $1.6 \times 10^{18} \text{ cm}^{-3}$ and N+ doping with $1 \times 10^{20} \text{ cm}^{-3}$ at P junction length with 28 nm, which gives better feasibility for junction fabrication. In this condition, the drive current and on-off ratio are over 20 A and 10^6 at 3V, respectively. This result gives us reasonable on/off ratio. However, the drive current is still a little lack of required current in practical work. This problem can

be overcome to use the other material with higher mobility than Si such as a SiGe.

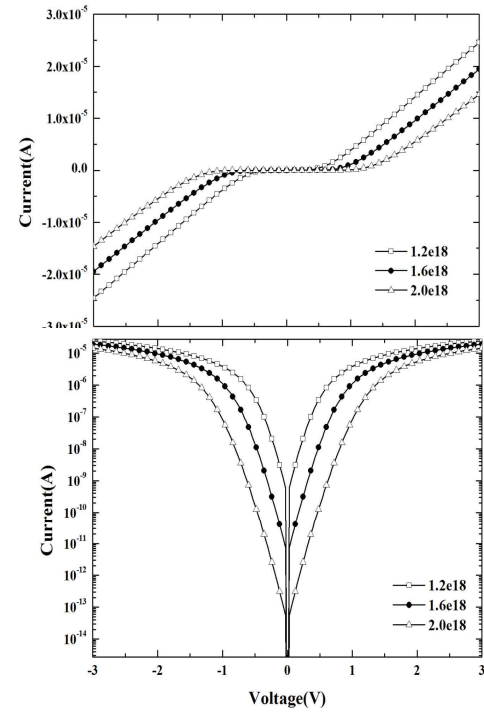


Fig. 3 I-V characteristics for variable P doping of N+/P/N+ Si junction device: N+ layer with $1 \times 10^{20} \text{ cm}^{-3}$, P junction length with 28 nm length.

3. Conclusions

We proposed a two terminal bidirectional switching device for scalable STT-MRAM, which consists of N+/P/N+ Si junction structure. A N+/P/N+ Si junction device was investigated in view of longer P-length for better process feasibility. From the simulation result, it is expected that a bidirectional junction structure can be one of solutions for a switching device in STT-MRAM.

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