Nano-contact for small power consumption in phase change memory

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ABSTRACT

We have studied new concept phase change memory (PCM) with nano-contacts to reduce power consumption. Nano-contact has been achieved by using PS-PDMS block copolymer self-assembly. Using PDMS dots formed on large contact hole, nano-contacts were made of SiO_x by exposing O_2-plasma in O_2-RIE. In self-assembly experiments and phase change simulation, we can obtain following conclusion. 1) We could predict that the power of nano-contact PCM is estimated to a tenth consumption power of conventional PCM in switching. 2) Our experiments demonstrated the reduction as same as this estimation. 3) We found out edge effect on current density, which rapidly increased at edge of nano-contact.

Key words: Nano-contact, Phase Change, PCM, GeSbTe, Self-assembly, Block coplymer etc.

1. INTRODUCTION

We have studied small power consumption in phase change memory (PCM). In order to achieve small power consumption, there are some solutions such as selection of phase change material, heater structure, phase change memory structure, etc. So far, we have experiences that direct heating is very important and suitable to reduce power consumption of PCM rather than indirect heating. In addition of the direct heating, we more reduce it by decreasing phase change material volume [1]. Such a scaling-down depends on fabrication of contact hole, so that it also depends on lithographic method. The minimum contact hole may be 50-200 nm in diameter even with advanced lithography. We need other lithographic method to make small contact holes. Considering vertical type phase change memory, it is very difficult to reduce the diameter of contact hole with EB or optical lithography. The purpose of this study is to develop new concept PCM structure with nano-contact [2, 3] as shown in Fig. 1.

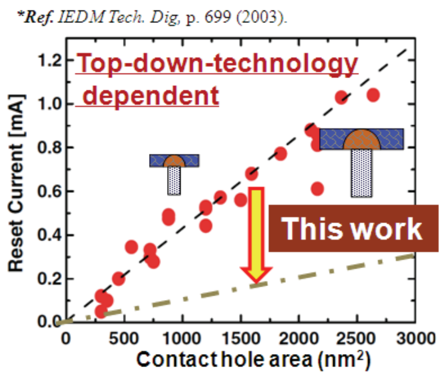

Fig. 1 Our final goal and conventional PCM in reset current for contact hole area.

In order to reduce the contact hole, we use nano-contact between the phase change material and heater instead of decrease of phase change material volume. Our idea is that insulate nanodos are inserted to the interface between phase change material layer and heater. We use self-assembly with block copolymer, PS-PDMS (polystyrene-poly dimethile siloxane) as a fabrication method of the insulate nanodots. In this paper, we describe the possibility to form the nano-contacts using PS-PDMS self-assembly [3-6] and to reduce switching power of PCM.

2. PHASE CHANGE MEMORY with NANO-CONTACTS

In order to reduce a power consumption of PCM, there are some methods such as selection of phase change materials, the device structure, etc. Basically, as we have to supply small power to device and heat up local phase change area to melting point in reset mode, it is necessary to design resistance of partial or all phase change area high as shown in Fig. 2. In this study, we treat with the structure with vertical type PCM with phase change material and heater in cascade connection

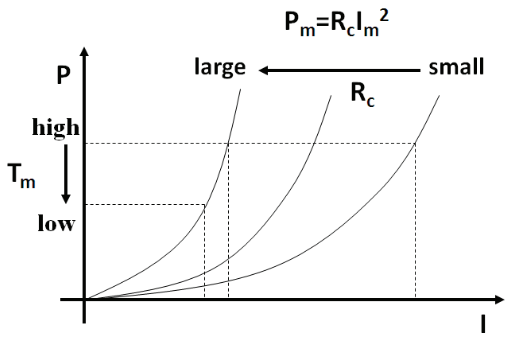

Fig. 2 Method of reduction of a heating power in phase change memory in its electric property.

(Fig. 3) as a conventional PCM. And the maximum heating position is around a center of the heater. As it is a little far from the phase change material, the conventional PCM has a disadvantage that large consumption power is required in reset process. In order to solve the problem, we utilize nano-contacts in interface between phase change material ($Ge_2Sb_2Te_5$) and TiN heater using PS-PDMS block copolymer self-assembly as shown in Fig. 4 [2]. By inserting nano-contact structure, the resistance of the interface and local phase change material, which is O_2-doped by the self-assembly process as described later, becomes larger than that of heater (Fig. 5). Consequently, we expect to heat up the interface and the phase change material part directly to contribute reduction of the power consumption. In this study, as the interface size is 90 nm in diameter, the self-assembled dot diameter is required to be about 10 nm.

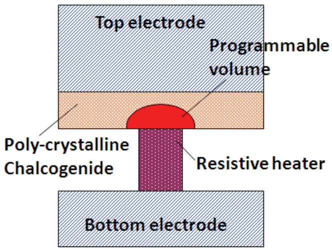

Fig. 3 Cross sectional view of the basic conventional vertical PCM structure.

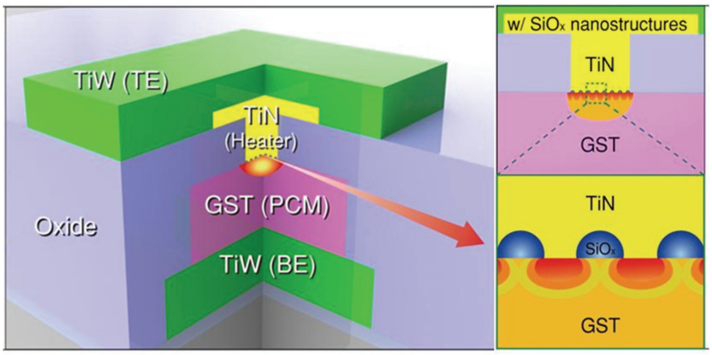

Fig. 4 Scheme of proposed nano-contact PCM with small insulated dots on interface between GST and TiN heater.

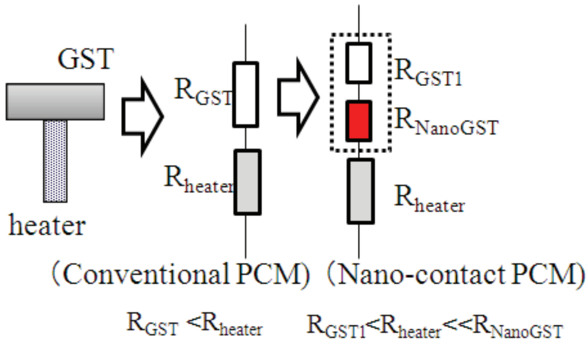

Fig. 5 Equivalent resistance circuits of conventional PCM and nano-contact PCM.

3. EXPERIMENTS

We have designed the proposed PCM and its fabrication process, especially in the self-assembly. As described above, new PCM has nano-contacts in the interface. For nano-contacts, there are some kind patterns of sphere, cylinder, lamellar, hole, etc. in self-assembly as shown in Fig. 6 [2]. As the dot etc. may be made of SiO_x in final stage, we predict that SiO_x edge effect appears as edge current density is enhanced as described latter. In the experiments, we used PDMS spheres. Especially, we describe self-assembly for nano-contact in this section as following.

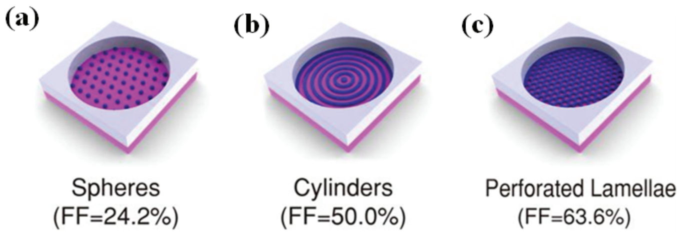

Fig. 6 Various shapes self-assembled by PS-PDMS block copolymer. FF is fill factor.

In the self-assembly, we have to select spherical shape and the diameter of < 20 nm. These requirements are decided by theoretical and experimental microphase separation of block copolymer of PS-PDMS. We studied fine dot size and pitch regarding the molecular weight (MW) of PS-PDMS based on theoretical relationship between the product of χN (χ: Flory-Huggins parameter and N: total number of segments) and the PDMS concentration ratio of block copolymer for total MW [7]. 4 kinds of PS-PDMS MW were selected as shown in Fig. 7. Using the self-assembly process including annealing and reactive ion etchings (RIEs) (Fig. 8), we obtained very fine dots and pitches of self-assembled PDMS dots as shown in Fig. 9. The figure shows a change of average dots pitch and dot size of 12-33 nm and 6-22 nm in using of PS-PDMS MWs of 7000-1500 to 30000-7500 g/mol, respectively. The dot size and pitch are determined by PS and PDMS molecular segment N as shown in Fig. 10. The self-

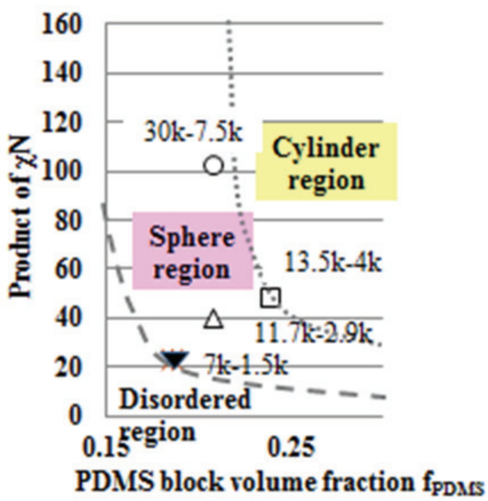

Fig. 7 Configuration of BCP self-assembled nanostructures and the PS-PDMS molecule weights used in the experiments.

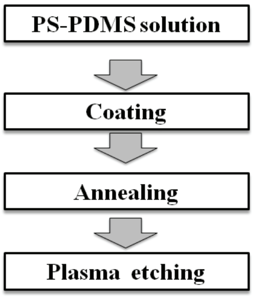

Fig. 8 Process flow of self-assembly with PS-PDMS.

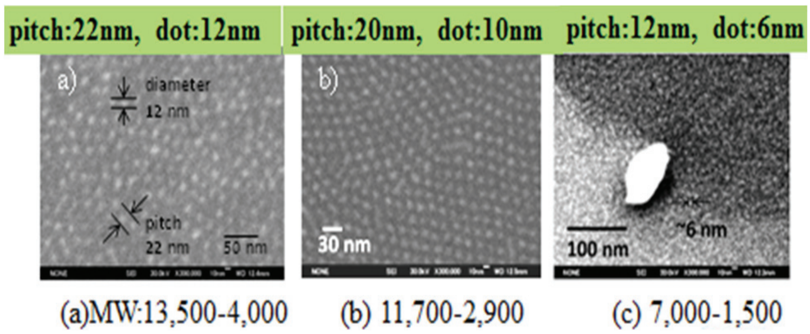

Fig. 9 SEM images of self-assembled PDMS dots using its MWs of 13500-4000, 11700-2900 and 7000-1500 g/mol.

assembled pitch and dot diameter decrease in a proportion to two thirds order of the N value. The value agrees well with theoretical result. On the other hand, we notice the self-assembly process. In final stage (Fig. 8), we did the RIE of phase change layer exposed with O_2 plasma. Consequently, the phase change surface in the interface was changed to oxide-doped phase change layer with several nm in depth.

4. RESULTS AND DISCUSSION [2, 3]

With our proposed device, the power reduction was studied by simulation using FEM (finite element method). We used the PCM structure as shown in Fig. 4. Figure 11 shows estimated current density, electrical potential and temperature of the nano-contact PCM and temperature of conventional PCM when we applied a current of 100μA (10ns) between top and bottom electrodes [3]. In the simulation, the nano-contact PCM and conventional PCM resistances changed about 10^4 to 10^7 Ω and 10^3 to 10^6 Ω, respectively, in reset process. When applying the current, current density increases local hole area with a diameter of 10 nm. Especially, we can observe edge effect that current density increase at the edge of the dots rather than that with no nano-contact. The electric field is enhanced in small holes of the nano-contact. Consequently, electric power concentrates to nano-contact and the O_2-doped GST layer. The temperature increases to over the melting point in the nano-contact device. However, conventional PCM's temperature increases a little to 320 K, which is too insufficient for melting of GST. Figure 12 shows estimated reset currents for top contact radius in both nano-contact PCM and conventional PCM [3]. As the current in nano-contact PCM reduces to a tenth of that in conventional PCM so that we can reduce the power of nano-contact PCM to a tenth magnitude of conventional PCM. In experimental results, we could demonstrate that the nano-contact phase change device achieve small power consumption reduction as same as the simulation described above [3].

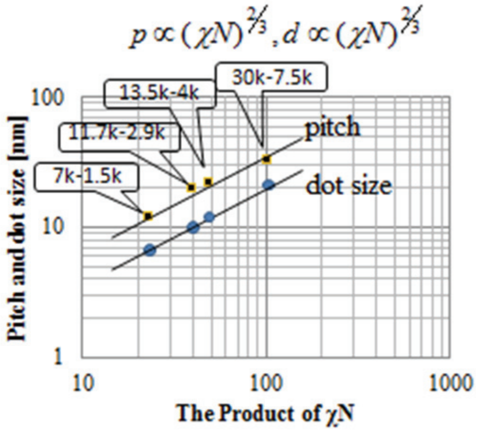

Fig. 10 Dot size and pitch for the production of χN.

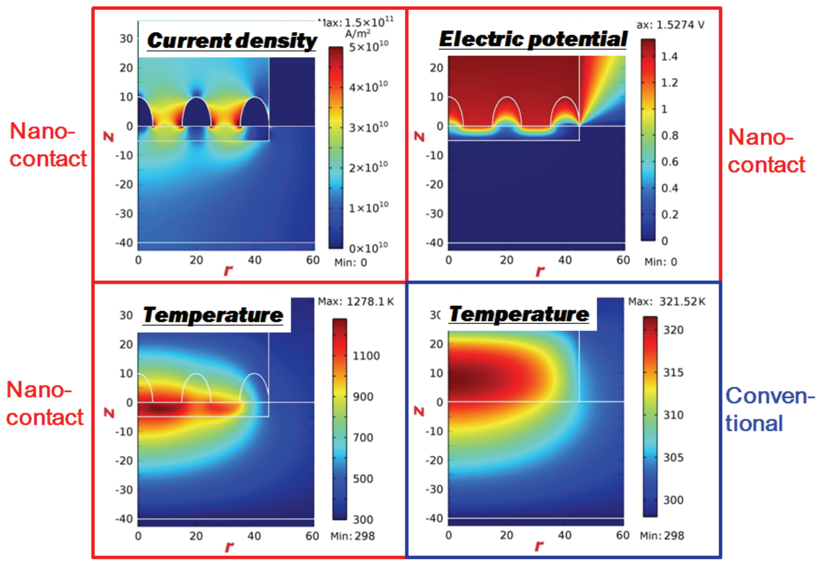

Fig. 11 Simulated results of current density, electric potential and heated temperature of nano-contact PCM, and heated temperature of conventional PCM.

4. CONCLUSION

We have studied new concept phase change memory (PCM) with nano-contacts to reduce power consumption. Nano-contact has been achieved by using PS-PDMS block copolymer self-assembly. Using PDMS dots formed on large contact hole, nano-contacts were made of SiO_x by exposing O_2-plasma in O_2-

RIE. As self-assembly experiments and phase change simulation, we obtain following information.

1) We predict that the power of nano-contact PCM is estimated to a tenth consumption power of conventional PCM. (Our experiments demonstrated the reduction as same as this estimation.)

2) We found out edge effect on current density, which rapidly increased at edge of nano-contact. By edge effect, we could select sphere structure from various shapes such as sphere, cylinder, lamellar, etc.

3) As the dot size of 10 nm in diameter, we have to select PS-PDMS with a MW of 11700-2900 g/mol.

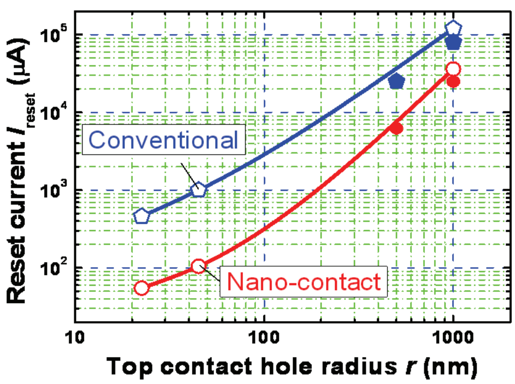

Fig. 12 Estimated reset current for top contact hole radius.

ACKOWLEADGMENT

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