Modeling of Triangular Sacrificial Layer Residue Effect in Nano-Electro-Mechanical Nonvolatile Memory

Min Su Han†, Yeong Hwan Kim†, Kyung Soo Kim†, Jae Min Lee†, Youngcheol Oh†, Woo Young Choi‡ and Il Hwan Cho†

†Department of Electronic Engineering, Myongji University, Yongin, Gyeonggi 449-728, Republic of Korea
‡Department of Electronic Engineering, Sogang University, Seoul, 121-742, Republic of Korea

E-mail: †ihcho77@mju.ac.kr

Abstract The effect of a sacrificial layer residue on a cantilever beam in the nano-electro-mechanical nonvolatile memory is investigated for the optimization of reliability characteristics. Different from previous research, pull in voltage model of nano-electro-mechanical nonvolatile memory used triangular residue layer which is considered by real wet etching process. Modified pull in voltage model was investigated with triangular shape sacrificial layer residue.

Keyword Nano Electro Mechanical Nonvolatile Memory, pull in voltage

1. Introduction

The Nano-Electro-Mechanical nonvolatile memory (NEMory) is one of the alternative memories came to the fore as a low power memory. Furthermore, the NEMory has advantages on low program/erase power and large sensing margin [1]. It can be adopted integrated device such as T-cell or H-cell structures for high density of the chip [2][3].

The NEMory can be operated by electro static force to control electric current and data storage using the position of the metal cantilever. Therefore, the space between the cantilever and the electrode is very important factor to set operation voltage and reliability. The space between the cantilever and the electrode is formed by wet etch process to eliminate the sacrificial layer [4]. In a previous work, we made the potential model of the rectangular sacrificial layer residue and the cantilever material [5]. Actually, the rectangular sacrificial layer residue is impossible in real fabrication process. In this study, we try to consider the triangular sacrificial layer residue in accordance with real wet etch process by analytical modeling.

Fig. 1. (a) Structure of NEMory and dimensional parameters. (b) Structure of equivalent structure of NEMory with sacrificial layer residue and dimensional parameters.

2. Modeling Works

Residue and cantilever have different material properties. Thus, we have to consider two types of material properties. When two types of material are tied together, however, it can be expressed an equivalent structure as shown in fig. 1(c). An equivalent structure is for calculating the moment of inertia. The modified width of the sacrificial layer residue (Wresi') is determined by the Young’s modulus ratio of residue and cantilever material following equation (1) [6]

\[ n = \frac{E_{resi}}{E_{beam}}, \quad W_{resi}' = nW_{resi} = \frac{E_{resi}}{E_{beam}} \times W_{resi} \quad (1) \]

To determine the moment of inertia at the center of an equivalent structure (Peq), an equivalent structure height (h1) at the cantilever and an equivalent structure height
The moment of inertia of the equivalent structure from equation (2)–(6)

\[ I' = \frac{1}{12} W_{\text{beam}} l_1^3 + W_{\text{beam}} T_{\text{beam}} \left( h_1 - \frac{1}{2} T_{\text{beam}} \right)^2 + \frac{1}{36} \left( W_{\text{resi}} l_2^3 \right) + \frac{1}{2} W_{\text{resi}} T_{\text{resi}} \left( h_2 - \frac{2}{3} T_{\text{resi}} \right)^2 \]  

(7)

The cantilever and triangular sacrificial residue have their own spring constant when they move up and down. Thus, we should consider the spring constant. The spring constant of the cantilever has a rectangular cross section is expressed as [7]

\[ k_c = \frac{2}{3} E W \left( \frac{l}{T} \right)^3 \]  

(8)

Equation (8) can be expressed by the moment of inertia as shown by [7]

\[ k_c = \frac{4E_{\text{beam}} I'}{I_{\text{beam}}^3} \]  

(9)

By using the moment of inertia of the equivalent structure shown in equation (7), the modified spring constant is expressed as

\[ k_c' = \frac{8E_{\text{beam}} I'}{I_{\text{beam}}^3} \]  

(10)

The pull-in voltage of the cantilever type is analytically calculated by using equation (11) [8]

\[ V_{pf} = \frac{8k_c}{27 \varepsilon_0 W_{\text{beam}} L_{\text{beam}} G^3} \]  

(11)

Where \( \varepsilon_0 \) is the vacuum permittivity, \( G \) is space distance between the cantilever and the electrode. The pull-in voltage of the equivalent structure can be calculated from the spring constant in accordance with equation (10). The pull-in voltage of the cantilever and the sacrificial layer residue can be expressed using all of previous equations. The final equation of pull-in voltage for cantilever and triangular sacrificial layer residue is expressed at equation (12).

\[ V_{pf} = \frac{8k_c}{27 \varepsilon_0 W_{\text{beam}} L_{\text{beam}} G^3} \]  

(12)
4. Conclusion

The triangular sacrificial residue which is considered by real wet etching process has been investigated by analytical modeling. The proposed model with triangular residue shape shows better accuracy than rectangular residue shape in previous work. The optimized model using triangular residue shape is expected to be helpful to design cantilever considering real wet etching process for the reliability of NEMory.

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