NUMERICAL ANALYSIS OF THEORETICAL MODEL OF THE RF MEMS SWITCHES

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ABSTRACT: An improved electromechanical model of the RF MEMS (radio frequency microelectromechanical systems) switches is introduced, in which the effects of intrinsic residual stress from fabrication processes, axial stress due to stretching of beam, and fringing field are taken into account. Four dimensionless numbers are derived from the governing equation of the developed model. A semi-analytical method is developed to calculate the behavior of the RF MEMS switches. Subsequently the influence of the material and geometry parameters on the behavior of the structure is analyzed and compared, and the corresponding analysis with the dimensionless numbers is conducted too. The quantitative relationship between the presented parameters and the critical pull-in voltage is obtained, and the relative importance of those parameters is given.

KEY WORDS: RF MEMS, axial stretching, residual stress, fringing field, critical pull-in voltage

1 INTRODUCTION

In recent years, the MEMS (microelectromechanical systems) technology has grown rapidly all over the world. The RF (radio frequency) MEMS is relatively new one which has already generated a tremendous amount of excitement because of the enhanced performances and reduced cost[1]. As novel device, the RF MEMS switches have a myriad application future in wireless communication and radar system[2~4]. Compared with conventional switches widely used in microwave and monolithic microwave integrated circuits (MMICs) such as p-i-n (PIN) diodes and field-effect transistor (FET) switches, the RF MEMS switches offer high isolation, high frequency, good Q-factor, low return loss, low insertion loss and power consumption.

Since the membrane-based switch on silicon reported by Petersen[5] as early as 1979, lots of researches based on various structures, fabrication processes, and activated principles have been reported[1]. The switch we study is electrostatically actuated and is doubly supported. A doubly supported RF MEMS switch usually consists of two parallel plates. One plate is fixed on the substrate and the other is formed by Au or Cu thin film prepared by electroplating process. A schematic of a doubly supported RF MEMS switch is shown in Fig.1. While a bias voltage is applied between the fixed and movable plates of switch, the movable plate could move down onto the fixed substrate subjected to electrostatic force. The device controls mechanical electric current or signal by using the on/off impedance radio. When the threshold (pull-in) voltage is reached, the switch is in the down state or blocking state, and when no voltage is applied it is in the up state or pass-through state.

An accurate theoretical model may efficiently lead the design and computation, and reduce the re-

* The project supported by the National Natural Science Foundation of China, the Chinese Academy of Sciences, the RGC/NSFC Joint Research Scheme (N-HKUST 601/01) and the Joint Laboratory of Microsystems
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search duration. Presently the theory and model of the RF MEMS switches is mainly established on the conventional theories. The mostly referred formulation of critical pull-in voltage is

$$V_{pi} = \sqrt{\frac{8KE_0g_0^3}{27\epsilon_0A}}$$

which is derived from a 1D lumped model. However, by considering the miniaturization of structure and the coupling field effect, some new influential factors should be incorporated into the analysis of behavior of the RF MEMS switches, such as intrinsic residual stress from fabrication processes, axial stress due to stretching of beam, and fringing field effect. The relevant theory containing those factors was proposed\cite{6}, while numerical analysis of the RF MEMS switches was conducted by using FEM, BEM, or Shooting method\cite{7,sl}.

In present paper we firstly by present a concise induction and analysis on our theoretical electromechanical model and the relevant influential factors. Subsequently based on the model, numerical calculation using a semi-analytical method is performed. The relationship between the characteristic of the RF MEMS switches and the relevant parameters is then further studied.

2 THE FORMULATIONS OF VARIOUS FACTORS

A simplified schematic drawing of the doubly supported switch is shown in Fig.2, where the transverse deflection \( w \) is uniform along the width of the movable beam, i.e., independent of the width. The middle point is defined as origin of the coordinate system. Because of the miniaturization, the couple field effect, and the special fabrication technology, the axial stretching of movable beam, the residual stress, and the fringing field effect have to be taken into account, respectively or simultaneously. Various influential factors\cite{6} are presented concisely in this section.

2.1 Axial Stress Due to Axial Stretching

The stretching is inevitable while a doubly clamped beam is bent. In some cases such as the maximum deflection less than the thickness of the beam, the stretching may be ignored. But for the RF MEMS switches, the original gap between two plates is often equal to or even larger than the thickness of the movable beam. Thereby the axial stress induced by the elongation of the movable beam has to be considered for more accurate models.

While a voltage is applied, the axial force \( T_a \) resulted from the elongation of the clamped beam is approximately given by

$$T_a = \frac{\vec{E}bt}{2l} \int_{-l/2}^{l/2} \left( \frac{dw}{dx} \right)^2 dx$$

where \( \vec{E} \) is the equivalent modulus of the movable beam, and \( b \), \( t \) and \( l \) are the width, thickness, and length of the movable beam, respectively. For a narrow beam \( \vec{E} = E \), where \( E \) is Young’s modulus. For a wide beam \( \vec{E} = E/(1-\nu^2) \), where \( \nu \) is Poisson’s ratio\cite{9}.

2.2 Residual Stress Inherent in Microstructures

Residual stress is derived from the mismatch of both thermal expansion coefficient and crystal lattice period between the substrate and the upper beam during the fabrication processes\cite{10,11}.

Residual force may be formulated as

$$T_r = \dot{\sigma} bt$$

where \( \dot{\sigma} \) is the residual stress, equal to \( \sigma_0(1-\nu) \) for a doubly supported beam, where \( \sigma_0 \) is the biaxial residual stress.

2.3 Fringing Field Effect

A uniform magnetic or electric field cannot drop abruptly to zero at its edge, so a “fringing field” as shown in Fig.8 of Ref.[6] always exists in real situations. The fringing field is denoted by its first order correction, which is given as\cite{10}

$$F_f = 0.65 \frac{g_0 - w}{b}$$

Fig.2 A schematic of the movable beam in a doubly supported switch