

Progress of (Sr, Ba) TiO₃ ferroelectric thin film and tunability

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Abstract. The fabrication method, technology route and structure performances of (Sr, Ba) TiO₃ (SBT) ferroelectric thin film have been summarized in this paper. The tunability of dielectric constant, dielectric loss and leakage current are the basic parameters of tunable microwave devices. The thin films of SBT with high properties could be fabricated by means of RF magnetron sputtering and sol-gel processing. The electrical performances of thin film material can be improved largely by dopants. Some problems are put forward to pay attention to this material research process.

Keywords. (Sr, Ba) TiO₃; ferroelectric thin films; sol-gel; tunability; dielectric loss.

1. Introduction

Since the late 1960s and early 1970s, the ferroelectric material applied in the automatic tunable microwave devices has been receiving renewed attention, and a number of practical tunable microwave devices were enamelled over the past several decades. It is generally agreed that, for applications in electrically tunable microwave devices, ferroelectric should be in a paraelectric phase, and not in the polar phase. The reason is that most of the ferroelectrics in polar phase are piezoelectric, and piezoelectric transformations could cause huge losses at relatively low microwave frequencies (typically < 10 GHz). Additional losses in polar phase at low frequencies are associated with the domainwall movement. Hysteresis, which appeared in permittivity–d.c. field dependence, is another reason hindering the application of a ferroelectric in a polar phase. Hence, no experimental reports have been published in the past to make electrically tunable microwave devices utilizing the ferroelectric phase. But the recent experiments have proved that such viewpoint is incorrect, for example, low microwave losses along with substantial tunability of the dielectric permittivity are observed in ferroelectric, Na_{0.5}K_{0.5}NbO₃ thin films, at 50 GHz (Abadei *et al* 2001). This indicates that at millimeter-wave frequencies, the domainwall movements and piezoelectric transformations do not contribute to microwave loss. Additionally, theoretical and experimental investigations in the past couple of years have shown that thin films, typically regarded as paraelectrics, may exhi-

bit inducing of strain in polar phase (Pertsev *et al* 2000; Gevorgian *et al* 2001). Thus applications in microwave devices of ferroelectrics in polar phase may offer additional functions and design flexibility. The tunability and loss tangent of ferroelectrics in polar phase, for application in tunable microwave devices are typical parameters, and the microwave losses are the response of loss tangent. Most of the efforts in recent years have been devoted to the optimization of fabrication processes of thin films in terms of microwave loss reduction. Sr_{1-x}Ba_xTiO₃ (SBT, in paraelectric phase, $x < 0.5$) is one of the important ferroelectric materials which has been extensively used in electronically controlled microwave devices. Microwave property, preparation process, structure and phase transition are discussed in this paper.

2. Microwave properties

Tunability and loss tangent are main properties of ferroelectrics for wide applications in tunable microwave devices, i.e. the ferroelectric thin film must possess the maximum tunability and minimal dielectric loss. The tunability of ferroelectric thin film indicates the d.c. voltage dependence of dielectric constant (or capacitance) and voltage. Spartak and Kollberg (2001) showed the tunability capacitance, $T_C(V) = [C_{(O)} - C_{(V)}]/C_{(O)}$, as the assessment parameter of devices rather than dielectric constant, $T_e(V)$, they also being effective assessment parameters of the material under some circumstances. For sandwich-type capacitors (bulk or thin film), $T_C(V)$ is approximately the same as $T_e(V)$, while it is smaller than $T_e(V)$ for planar capacitors on the existence of gap between electrodes and surface of a ferroelectric thin

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film. Al-Shareef *et al* (1997) showed the tunable coefficient of the tunable microwave devices as

$$\text{Fom} = [\% \text{ tunability} = (C_{\max} - C_{\min})/C_{\max}]/\tan \mathbf{d} (\%),$$

where C_{\max} is the maximum capacitance and C_{\min} the minimum capacitance over the investigated voltage range, and $\tan \mathbf{d}$ is dissipation factor. It indicated that these coefficients are as high as possible, while previously reported values had typically been < 50 . If the dissipation factor was high, it reflected the fact that a tunable microwave circuit could not achieve the optimal tunable coefficient even though higher capacitance tunability (% tunability) was in the range of applied voltage. Thus the loss factor of thin film should be as low as possible.

At the initial stage, measurement of the dielectric loss tangent for ferroelectric material–single crystal was carried out by using samples without electrodes, but with electrodes in sandwich configuration, in case where superconductor electrodes were used, the losses associated with the electrodes were ignored. Microwave measurements of the dielectric properties of epitaxial thin films were done using planar electrodes applied to one surface of the film only, but no contact loss microwave measurement of ferroelectric thin films have been reported thus far, which made it difficult to distinguish between the losses in the bulk of thin film and at the film/ferroelectric interface. For the sandwich-type capacitor structures, for example, in planar capacitors, a considerable part of the microwave field was outside (such as in air) the ferroelectric film or in low dielectric loss substrate, which means that measured effective dielectric constant, tunability, and loss tangent were lower than that of the thin film itself. In most cases, these losses were ignored since they were usually smaller in comparison with the losses in the ferroelectric thin films, while the actual losses in the bulk of the film were still higher in comparison with the bulk single crystal, especially at room temperature. Thus by optimizing the various preparation technology parameters and choosing various electrode materials to improve dielectric constant and tunability of material and reduce loss of thin film capacitor are still the major problems in tunable microwave devices which need further attention.

3. Preparation technology

There are many methods for thin film (Sr, Ba) TiO_3 preparation, such as metal organic chemistry vapour deposition (Watanabe *et al* 2001), pulse laser deposition (Wu and Barnes 1998; Kim *et al* 2000), magnetron sputtering (Izuha *et al* 1998; Panda *et al* 1999; Kim *et al* 2000; Lee and Tseng 2002) and sol–gel (Tahan *et al* 1996; Bao *et al* 1999; Ding *et al* 2000; Giridharan *et al* 2000). Thin film with high properties could be fabricated by these methods, and comparatively perfect processing parameters were formed for these methods. The RF magnetron sput-

tering and sol–gel processing are the simple preparation methods for thin films with higher quality, and they are given priority for fabrication of thin film by research workers. Therefore, this paper focused on the introduction of RF magnetron sputtering and sol–gel processing.

3.1 Magnetron sputtering technology

RF magnetron sputtering technology has been used widely in preparing thin films. Under low pressure, the probability of sputtering the scattered atoms is small, thus the deposition speed using this method is higher by an order of magnitude than others. Besides, the probability that gas molecules and electronics collide each other has effectively been raised in the magnetic field. So the pressure of working atmosphere and the trend of thin films polluted are reduced remarkably. At the same time, the energy of atoms on the surface of the target obtained from the electrics, is raised, thus improving quality of the thin film to a great extent.

3.1a Influence of working pressure: The property and structure of thin films are studied by various parameters of RF (radio frequency) magnetron sputtering technology such as substrate temperature, total pressure of working atmosphere, Ar : O₂ ratios of partial pressure, RF power, the composition of the target, type of substrate and electrode. Kim *et al* (2000) studied the effects of total pressure of working atmosphere on composition and properties of thin films of $\text{Ba}_x\text{Sr}_{1-x}\text{Ti}_{1+y}\text{O}_{3+z}$. Using $\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$ as the target, the film of $\text{Ba}_x\text{Sr}_{1-x}\text{Ti}_{1+y}\text{O}_{3+z}$ was prepared by RF magnetron sputtering, whose thickness was 80 nm. When O₂/Ar ratio was fixed at 1/5, the ratios of (Ba + Sr)/Ti changed with a variation of the total gas pressure from 22–58 mTorr, and the deposition composition was deviated from the target composition, while the variation of P_{O₂} : P_{Ar} ratios had little effect on composition chemistry of thin films. The thin films exhibited a dense surface, polycrystal structures, high dielectric constant (420–530), high tunability (74%) when (Ba + Sr)/Ti ratios were > 0.85 , while the lower dielectric loss (0.0047) was found for the sample with a (Ba + Sr)/Ti ratio of 0.73.

3.1b Influence of thickness: Panda *et al* (1999) investigated the relationship between dielectric constant and thickness of thin films. $\text{Ba}_{0.8}\text{Sr}_{0.2}\text{TiO}_3/\text{Pt}/\text{TiN}/\text{Ti}/\text{SiO}_2/\text{Si}$ thin film capacitor was deposited by RF magnetron sputtering. The dielectric constant was found to increase with the increasing thickness of the film, a space charge layer with low dielectric constant was also found to form at the film electrode interface. The deposition temperature and the type of substrate determines the growth and orientation of thin film.

3.1c Influence of oxide electrodes: Izuha *et al* (1998) studied how the oxide electrodes affected the dielectric

constant and other properties by RF magnetron sputtering. Using SrRuO₃ (100/nm) as top and bottom electrodes, SrTiO₃ (100/nm) as substrate, the thin films of single-crystal Ba_{0.12}Sr_{0.88}TiO₃ (20/nm) and epitaxial Ba_{0.5}Sr_{0.5}TiO₃ (20/nm) were prepared and their dielectric constants (681 and 274) and leakage current were measured, respectively. It was found that oxide electrodes had high effect on properties of thin films only when (i) the lattice constant of electrode was less than that of the dielectric, (ii) thermal expansion coefficient of electrodes was larger than that of the dielectric, (iii) electrode material had the same crystal structure as the dielectric and higher dielectric permittivity was obtained by lattice extension in the C axis direction.

3.1d Influence of dopants: Similarly, a fair advancement had been made in determining the effects of dopants on the properties of thin films by RF magnetron sputtering. For example, Lee and Tseng (2002) reported that thin films with 5 mol% MgO doped in Ba_{0.7}Sr_{0.3}TiO₃ (BST) were prepared on Pt/TiN/SiO₂/Al₂O₃ by RF magnetron sputtering, the dielectric constant having been raised remarkably and the leakage current density of film reduced by an order of magnitude. When the Mg content was higher than 5 mol%, dielectric constant (from 450–205) and tunability of the films decreased and dielectric loss and leakage current increased. So the 5 mol% MgO dopant was an excellent choice for tunable microwave devices. By selecting the optimum processing parameters, thin film with high quality that are applied for microwave devices could be prepared by RF magnetron sputtering.

3.2 Sol-gel processing

Sol-gel processing is a wet chemical method for preparing ferroelectric thin film, i.e. metal alkoxide was dissolved in organic solvent and homogeneous solution was prepared through the addition of other components and chelating agents. Inorganic thin films with some thickness are prepared by coating solution on substrate, drying, thermal decomposition and annealing at certain temperature. In comparison with other methods of preparing thin film, sol-gel possesses unique superiorities: (i) the reaction is in solution, and chemical uniformity is at the molecular level for many components, (ii) heat treatment (annealing) temperature is lower than the traditional methods, (iii) stoichiometric ratio is accurate, and is easy to modify, (iv) it can be optimized according to the requirement of properties for thin film and amount of the dopant are wide, (v) processing is simple, low cost, and easy to popularize and (vi) thin film with big area can be prepared, and the performances are stable. The technology route of thin film by the sol-gel processing is shown in figure 1.

3.2a Influence of precursor compounds: The precursor solutions are first prepared from the precursor com-

pounds that offer Sr, Ba and Ti in sol-gel processing. These compounds are generally strontium acetate, barium acetate, titanium acetate, titanium isopropoxide, titanium (iv) tetrabutoxide, Ba(OH)₂ and Sr(OH)₂. At present, the precursor compounds used are generally strontium acetate, barium acetate and titanium (iv) tetrabutoxide (Bao *et al* 1999; Ding *et al* 2000; Giridharan *et al* 2000), and these compounds have wide selection scope for organic solvent and higher solubility in the alcohol of short chain. The precursor solutions exist steadily for a long time.

3.2b Influence of solvents: The solvents affect directly the hydrolysis rate, solubility and gelatinization time of the precursor solutions and the volatility of the solvents also affects the porosity of the thin films. Generally, the condensation polymerization of organic precursors hardens the thin film and evaporation and raising evaporation rate contribute to the density of the thin films prepared. If evaporation speed is too fast, holes and cracks are created in the homogeneous thin films. The solvents constantly in use are propyl alcohol, isopropanol, methanol, ethylene glycol, glacial acetic acid, 2-methoxyethanol etc. The dissolving capability of anhydrous alcohol in the majority alkoxide is higher than others, and difficult to change with -OR of alkoxide. The glacial acetic acid not only has bet-

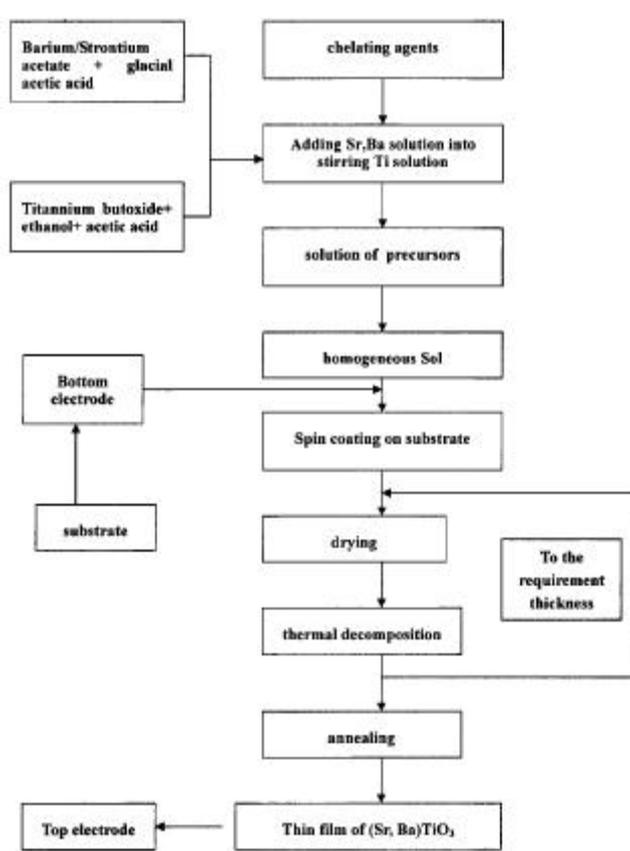
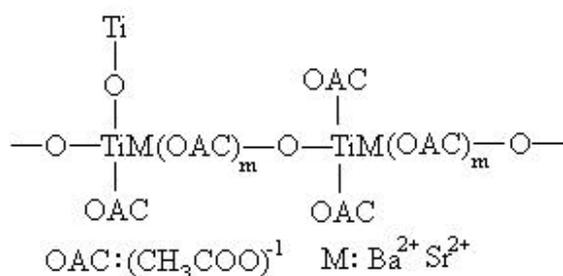
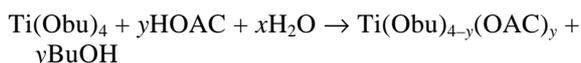
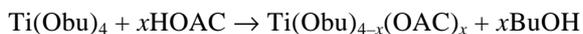


Figure 1. Technology route of fabrication of thin film by sol-gel processing.

ter dissolving capability to alkoxides and inorganic salts, but also can be effective to adjust the hydrolysis and condensation polymerization rate of titanium (iv) butoxide. Thus, these two solvents are constantly used. The reason why solution forms sol is that the multipolymerization occurs between glacial acetic acid and the titanium (iv) butoxide. The chemical reaction equations can be described as follows:



The reaction rates mentioned above determine the change of speeds of sol and gel.

3.2c Influence of chelating agents: For the sake of stocking the precursor sol for a long time, preparing stable sol, modifying viscosity and improving the sintering properties of thin films, some chelating agents and surface active agents are added in the course of preparing sol. The chelating and surface active agents used are generally acetylacetone, diisopropanolamine, triethanolamine, propanetriol, ethanolamine etc. Selvaraj *et al* (1991) prepared SrTiO₃ thin films on the substrate of melting quartz (silica glass), and it was found that diisopropanolamine was a better chelating agent than triethanolamine, acetylacetone and alkanolamine. Ding *et al* (2000) discovered that the perovskite phase was formed through the reaction of solid phase without chelating agents, but when they studied the influence of chelating agents (acetylacetone and acetic acid) on the crystallization, density and homogeneity of the Ba_{0.7}Sr_{0.3}TiO₃ thin film, the perovskite phase was formed by the transformation of middle phase, (Ba_{1-x}Sr_x)TiO₂CO₃, with acetylacetone and acetic acid. The polymerization of Ti (OC₄H₉)₄ was inhibited, the deviation between Ti, Ba and Sr was avoided, the uniformity and dense structure were obtained, and acetylacetone was found to be a better chelating agent.

3.2d Influence of substrates and electrodes: The substrates and electrodes also are important factors that affect the high quality of thin film derived from (Ba, Sr) TiO₃. When thermal expansion coefficient and crystal plane structural parameters are equal approximately to that of (Ba, Sr) TiO₃, it is possible that thin film grows epitaxi-

ally and better quality thin film is prepared. There are many substrates used frequently such as un-strain rigid wafer, molten quartz sheet, silicon blade, MgO, SrTiO₃, LaAlO₃ etc. The bottom electrodes on the substrate also seriously influence the structure of the thin film, since the interface layer has reduced the fatigue resistance of thin film, and increased dielectric loss and leakage current, the life time of thin film also has been reduced in use. The electrode materials used are noble metals, such as platinum, gold, palladium, nickel, and oxide electrodes, such as CaRuO₃, SrRuO₃, LaNiO₃ etc. Because the structure of the oxide electrode is perovskite, the lattice parameter and thermal expansion coefficient are similar to that of (Ba, Sr) TiO₃, the probability of lattice mismatching is small, and the resistance of this thin film is lower, when the thickness of CaRuO₃ and SrRuO₃ was ~70–300 nm, the resistances were 200 μΩ cm and 280 μΩ cm, respectively (Higashi *et al* 2000). Thus the oxide electrodes are probably applied extensively to bottom electrode of the thin film. Izuha *et al* (1998) and Cho *et al* (1999) demonstrated that the dielectric constant raised the leakage current and dielectric loss descended by a wide margin, and remanent polarization approached 32 μ C/cm² when using SrRuO₃ and LaNiO₃ as the bottom electrodes of the thin film. Hybrid electrode and substrate technology are also applied in the course of preparing thin films, such as Pt/SiO₂/Si, Pt/SrTiO₃/MgO, Pt/TiN/SiO₂/Al₂O₃, Pt/Ti/SiO₂/Si, Pt/Ti/Si, CaRuO₃/SrTiO₃/Si and SrRuO₃/SrTiO₃/Si etc and metal iridium (Ir) replacing Pt (platinum) as the electrode becomes one trend of development (Angus and Stephen 1999). The application of these technologies will provide new methods for preparing thin film with high properties.

4. Structure of thin film

4.1 Crystal structure of (Ba, Sr) TiO₃

The studies on (Ba, Sr) TiO₃ microstructure concentrate on the crystal structure system, grain size distribution, domain structure, layers of regions, Curie temperature, growth mechanism of grain, lattice mismatch, strain and the influence of dopants on structure and performance etc. (Sr, Ba) TiO₃ crystal exists as a cube and a tetragonal symmetry, transformation point of crystal system is the Curie temperature point, and if temperature is over the Curie temperature, it is cube perovskite symmetry (paraelectric phase, the XRD data is by reference to the JCPDS card of Ba_{0.5}Sr_{0.5}TiO₃, No. 39-1359), otherwise it is tetragonal symmetry (polar phase, the XRD data is by reference to the JCPDS card of BaTiO₃, No. 5-626) below the Curie temperature point. The distribution of Sr²⁺, Ba²⁺, Ti⁴⁺ and O²⁻ ion in crystal cell is shown in figure 2. Sr²⁺ and Ba²⁺ ions are located in the eight angular point seats of cubic crystal cell, and O²⁻ ion is located in the face centre of

the three pairs of parallel faces, while Ti⁴⁺ is located in the cube centre of cubic cell.

4.2 Influence of dopant

In crystal structure of (Ba, Sr) TiO₃, ions in locations A and B can be replaced by other ions with different electric charges and radii, but the relation between the ion radii must satisfy

$$0.77 < t = (r_A + r_O)/(2^{1/2}(r_B + r_O)) < 1.10,$$

where r_A is A ion radius, r_B the B ion radius, r_O the O²⁻ ion radius, t the allowance tolerance factors. As $r_{Sr} = 0.144$ nm (coordination number is 12), $r_{Ba} = 0.131$ nm (coordination number is 12), $r_{Ti} = 0.061$ nm (coordination number is 6), and $r_O = 0.140$ nm (coordination number is 6), the $t_{Sr} = 0.9992$, $t_{Ba} = 0.935$, both are located in the allowance factor scope, and the structure is stable. At the same time two kinds of metal ions, Sr²⁺ and Ba²⁺, can replace each other to form the continuous solid solution, leading to the changing of cell parameters and the Curie temperature point occurs, i.e. crystal lattice parameter increases from 3.905 Å to 3.994 Å with reduction of strontium content or the increase of barium content. The relationship of the bulk polycrystalline materials of (Ba, Sr) TiO₃ between Curie temperature and barium content was written as $T_C = 371x - 241$, and as far as the thin film material is concerned, the relationship between the largest or maximum dielectric constant temperature point and barium content is written as $T_C = 185.23x - 176.04$ (Tahan *et al* 1996); it had reflected that Curie temperature point or maximum dielectric constant temperature point changed with Sr/Ba ratios. The difference of Curie temperature point between the bulk polycrystalline and thin film is obvious, for example, the Curie temperature of Ba_{0.5}Sr_{0.5}TiO₃ thin film was 33.9–77.5°C, while the bulk polycrystalline material was –41°C (Cukauskas *et al* 2002), and BaTiO₃ epitaxial thin film was still tetragonal crystalline phase on

heating up to 600°C (Kim and Je 1999). Therefore, as for thin film material, the influence of the lattice stress, the lattice mismatch and the grain size distribution on Curie temperature, and crystal lattice parameter should be taken into account.

When the tolerance factor of dopants was located in the range of 0.77–1.10, the atoms of dopants replaced the atoms of location A or B, to form continuous solid solution, and the crystal lattice parameter, performance and sintering capability of thin film underwent important changes. In order to improve material capabilities, some modified ions were added in the course of preparing material. If acceptor dopant ions exist on the boundary of grain, the thin films possess low dielectric constant property and low leakage current. Donor dopant could improve the ability of fatigue endurance and leakage current resistance, and reduce the imprint etc. The microstructure of Ba_{0.6}Sr_{0.4}TiO₃ thin film (Cole *et al* 2001) with 1 mol% La dopant was nontextured polycrystalline with no evidence of secondary phase formation, the dielectric constant, resistance, tunability was 283, $31.4 \times 10^{13} \Omega \text{ cm}$, 21% (100 kHz, 300 kV/cm), respectively. The dielectric constant, tunability, and $\tan \delta$ of the Ba_{0.6}Sr_{0.4}TiO₃ thin film (Wu and Barnes 1998) with 1 mol% Mn were 2100, 85%, 0.0033 at room temperature, respectively. The dielectric constant and life time of PZT films with 3–4 mol% niobium or 4 mol% lanthanum (Al-Shareef and Dimos 1997) raised much more than that of PZT film with no dopant, the leakage current of stable state is lower by three orders of magnitude at least. Thus the modified elements at appropriate amount could improve dielectric properties of thin film.

4.3 Influence of stress

Because of the differences in the crystal structure parameters, thermal expansion coefficient for thin film and substrate (or electrode), the structure of thin film was

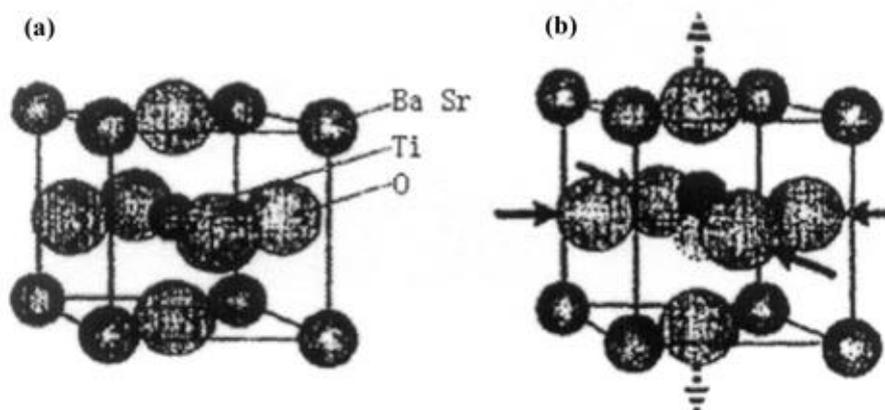


Figure 2. Cubic and tetragonal symmetry of (Sr, Ba) TiO₃: (a) BST in cubic and (b) BST in tetragonal.

affected by stress in the course of crystal particle growth or cooling or annealing, the *C* axis of crystal was outstretched, thus the crystal structure changed from cubic to tetragonal symmetry. Kim *et al* (2000) investigated the changing regularity of crystal structure type, dielectric constant, tunability etc in thin film of Ba_{0.5}Sr_{0.5}TiO₃ from the tensile stress to pressure stress. Because of stress, it was inclined to form tetragonal crystalline phase in polarization phase in the course of crystal growth. Curie temperature of (Sr, Ba) TiO₃ thin film was higher than that of bulk polycrystalline material at the same Ba/Sr ratios, and fine grains existed, their diameters no more than 100 nm for the growth of crystal grain suffered restrain. AFM image indicated that there exists tightly coupled grains structure, their diameters were 0.25 μm in cluster state and the diameters of numerous crystal grains were < 50 nm (Cukauskas *et al* 2002), thus it was found that decrease of average grain diameter induced increase of the Curie temperature.

4.4 Influence of grain size

The influence of grain size distribution on the Curie temperature of BaTiO₃ material can be shown as (Uchino *et al* 1989)

$$T_C = 128 - 700/(D - 110),$$

D serves as grain size (nm). It indicates that the Curie temperature (*T_C*) is gradually reduced obviously with the decrease of crystal diameter. Physical properties in a sub-micrometer particle sample are generally affected by two significant factors, one is a macroscopic effect related to the surface tension of fine particle, and the other concerns the particle size effect on the phenomenon of phonon softening which contributes to the spontaneous polarization of the material. Thus the grain size and the Sr/Ba ratios all influence on the Curie temperature point of thin film material.

4.5 Influence of interface structure

The interface structure between film and electrode or/and the substrate also is one of the important factors that influence the performance of film such as the roughness at the interfaces of Pb(Zr_{0.53}Ti_{0.47})O₃/yBaCu₃O_{7-d} which is approximately 1.7 ± 0.3 nm and the thickness in the region, non-switch area (Giridharan *et al* 2000), was 20 nm. The SiO₂ layer of 3.1 nm, Si of 5.6 nm, Sr and O_x layer exists on the SrTiO₃/Si interface, at the interface of Ba_{0.5}Sr_{0.5}TiO₃/SrRuO₃, it was difficult to distinguish the interface owing to the existence of continuous column crystal of 75 nm (Izuha *et al* 1998). The existence of the interface reduced the dielectric performance and the fatigue resistance of thin film.

5. Future direction

The progress being made to improve the dielectric constant (tunability) of thin film material and microwave loss is too slow in spite of researchers having put in lot of efforts in recent years. No matter what the preparative methods are and substrates of thin film material used, when compared to the single crystal materials, the dielectric constant is still lower, and the practical loss of tan *d*, whose order of magnitude is 0.01, is fairly large. But in some circumstances, effective tan *d* sometimes closes the single crystal material. Therefore, there is a need for more concerted effort by researchers to find a solution to this problem. First, thin films for application in tunable microwave devices should be prepared by improving and optimizing new processing techniques to obtain high performance, i.e. to increase the dielectric constant (tunability) and reduce leakage current and dielectric loss of thin film material. Secondly, the surface effect and the crystal grain dimension on the properties of thin film should be paid attention to, for the diameter of crystal grains that exist in thin films is about 100 nm, the interface of grain between film and substrate, or electrode, and the boundary among crystalline grains exist in the tunable capacitor, the properties of thin films are affected by small grains, interface and boundary greatly. Thirdly, the influence of the modified dopant ions on the thin film properties and structure should be given importance. The properties of phase transition, change of the unit cell constant, structure of electrical domain and change of the properties are also affected enormously by dopant ions. Therefore, the regularity of these changes is worth further study by researchers who go deep into the subject.

6. Conclusions

(Sr, Ba) TiO₃ thin film has bright prospect in application of tunable microwave devices and phase shifter switch, which is attracting the materials scientists to go deep into the subject, and direction one has to take in the study of thin film has already been formed. For this material possesses the characteristics of higher tunability in the Curie temperature, and higher dielectric constant, the ambient temperature of the material is comparatively broad. In spite of the dielectric constant, the dielectric loss and tunability of this thin film material are lower than that of single crystal material. With the advancement of the preparation technique and the perfecting of processing parameters for the thin film material, the high performance of (Sr, Ba) TiO₃ thin films matching with the single crystal material will certainly be achieved.

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