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学　位　論　文　名	Dielectric Property Control of Ferroelectric Thin Films for Applications to Infrared Sensor and Microwave Tunable Devices （強誘電体薄膜の誘電性制御と赤外線センサとマイクロ波チューナブルデバイスへの応用）
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論 文 内 容 の 要 旨

This thesis contains a study on ferroelectric materials in paraelectric phase suitable for applications in dielectric bolometer mode of infrared sensor and microwave tunable devices. The main purpose is to find suitable ferroelectric materials that held promises as top candidates for integration into devices from the area of interest, and to control their dielectric properties by optimizing the deposition conditions to achieve good dielectric properties to be used in dielectric bolometer mode of infrared sensor or microwave tunable device applications.

Selection of ferroelectric material by investigating their general behavior was the first step in this study because the requirements for ferroelectric materials to be used for dielectric bolometer mode of infrared sensor and tunable microwave application are different. It has been concluded that the most suitable candidate for dielectric bolometer mode on infrared sensor is barium titanate stannate, $Ba(Ti_{0.85}, Sn_{0.15})O_3$, and, for microwave tunable applications barium strontium titanate, $(Ba_{0.6}, Sr_{0.4})TiO_3$, is the most suitable candidate for this type of applications.

Having the ferroelectric candidates for dielectric bolometer mode of infrared sensor and tunable microwave applications selected, the next step was to control the dielectric properties of the selected films by careful considerations upon the deposition conditions. Metal-organic decomposition process technique was used to deposit the ferroelectric thin films as the best preparation method.

As a dielectric bolometer mode of infrared sensor candidate, $Ba(Ti_{0.85}, Sn_{0.15})O_3$ thin films deposited on $Pt/Ti/SiO_2/Si$ substrates have been investigated in order to obtain films with a large change in dielectric constant with film temperature while keeping the other electrical properties at acceptable values. The influence of the annealing and post-electrode-formation treatment temperatures as well as the influence of N_2 added during the spinning process has been investigated. As a result it has been found that $Ba(Ti_{0.85}, Sn_{0.15})O_3$ thin films deposited using 4 l/min N_2 flow during spinning, annealed at 700℃ and post-electrode-formation treated at 300 ℃ showed the largest change in dielectric constant with temperature, temperature coefficient of dielectric

constant (TCD) having values of more than 5.6%/K at 25℃ and being almost 11%/K at 20℃, value that is the highest reported so far. Integration of $Ba(Ti_{0.85}, Sn_{0.15})O_3$ into a simple structure of a dielectric bolometer mode of infrared sensor has been successfully obtained, and, after optimization of the operating conditions, the detection of a target with a temperature of 27℃ at room temperature (24－25℃) was possible. Voltage responsivity and specific detectivity were calculated to be 0.11 kV/W and 3×10^8 $cmHz^{1/2}/W$, being in the same range as other type of infrared sensors.

As a tunable microwave candidate, $(Ba_{0.6}, Sr_{0.4})TiO_3$ thin films deposited on MgO (100) substrates have been investigated in order to make highly dc-field-dependent dielectric constant as well as with very low dielectric loss. The influence of an interlayer and the film thickness, as well as the annealing effect on the tunability and dielectric loss has been investigated. It has been found that a 20 nm thick $(Ba_{0.6}, Sr_{0.4})TiO_3$ film (interlayer) deposited by pulsed laser deposition on MgO prior to the main deposition of the $(Ba_{0.6}, Sr_{0.4})TiO_3$ by metal organic decomposition process increases the tunability of the fabricated films while maintaining very low dielectric loss. Also, increase in metal-organic deposited film thickness enhances the value of tunability. Also, annealing performed when the newly deposited film thickness is only 35 nm in thickness, is an important condition to increase the tunability value. It has been found that films having a 20 nm interlayer and 700 nm total layer, annealed every after 35 nm of deposited amorphous $(Ba_{0.6}, Sr_{0.4})TiO_3$, showed a tunability of 11% at a frequency of 1 MHz on an interdigital electrodes capacitor at 40 V dc voltage applied. Dielectric loss measured in same conditions is below 0.006. By integration of the $(Ba_{0.6}, Sr_{0.4})TiO_3$ film into a tunable microwave device, in this casc a CPW-line-type phase shifter, shows a differential phase shift of －40 degree at 20 GHz when 0 and 60 V dc voltage is applied.

論 文 審 査 の 結 果 の 要 旨

強誘電体薄膜においてその誘電率の制御を利用した機能電子デバイス応用が期待されているが、中でも赤外センサとマイクロ波チューナブルデバイスは近年特に注目される応用分野である。本論文では、上記デバイス応用を念頭に、強誘電体材料の基本特性の検討から候補材料としてペロブスカイト結晶であるチタン酸バリウム $BaTiO_3$ 系材料に注目し、赤外センサ用には特に $Ba(Ti, Sn)O_3$（BTS）を、マイクロ波帯チューナブルデバイス用には $(Ba, Sr)TiO_3$（BST）を選定して、各々薄膜作製プロセスを検討した結果、良好な基礎特性を得た。さらに、赤外センサ、マイクロ波チューナブルデバイスのデバイス作製を行い、優れたデバイス性能を実現した。

まず、赤外センサ用の BTS の製膜プロセスの有機金属分解（MOD）法において、溶液塗布時の N_2 雰囲気の採用、塗布した単一層ごとの熱処理（700-800℃）、赤外検知キャパシタ上部電極形成後の低温熱処理（300℃）により、赤外センサ（誘電ボロメータ）の誘電率温度係数を 5 %/K と大幅に増大できた。その結果、赤外センサの赤外検知性能も大きく改善し、電圧感度 0.11 kV/W、比検出能 3×10^8 $cmHz^{1/2}/W$ が得られ、他の検出モードの赤外センサと同等以上の性能を確認できた。

次に、マイクロ波チューナブルデバイス用の BST 製膜でも主プロセスとして MOD 法を検討し、特に BST 初期核層を 20 nm 程度レーザーアブレーション法で形成しその上に MOD 法で上記単一層ごとの熱処理を採用することで、40 V 印加時で十分大きなチューナビリティ 11%、小さな誘電損失 0.002-0.006 が得られた。マイクロ波帯 20 GHz にて MgO 基板上同薄膜を用いたコプレーナチューナブルキャパシタでも 30 V 印加時 7-11%のチューナビリティを得た。また同層構造の標準コプレーナ線路構造移相器では 18° の位相シフト、挿入損失 2 dB を、またコプレーナ構造で専用設計した移相器では 40° の位相シフト特性を得た。

以上述べたように、本論文は、良好な誘電率制御が可能な強誘電体薄膜として、赤外センサ用に BTS を、マイクロ波チューナブルデバイス用に BST を選び、誘電率制御特性が優れる製膜プロセスを完成した後、それらから構成される良好な赤外センサ、マイクロ波チューナブルデバイスを作製し、優れたデバイス性能を実証したという重要な結果を得ており、学位（工学）論文として価値あるものと認める。