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Effects of thickness of the thermal insulation layer on the properties of $PbTiO_3$ thin films

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Abstract A multilayer pyroelectric thin film structure (MPTFS) is one of promising candidates for applications on uncooled IR focal plane array detectors. In the MLPTFS, a porous silica film is used as a thermal insulation layer, and the thermal insulation is improved with increasing thickness of a porous silica film. On the other hand, the effects of thickness of the porous silica films on the electrical properties of pyroelectric thin films need to be addressed. The research results have shown: the thickness of the porous silica films can not be increase unboundedly. With increasing thickness of porous silica films, the coercive field increase, the dielectric constant and the breakdown field decrease respectively. When the thickness of the porous silica films is lower than 3 μm, the effects of the porous silica films on the properties of PT thin films are acceptable. The optimized thickness of the porous silica films is determined according to the results of the electrical properties.

Keywords Multilayer pyroelectric thin film · Porous silica film · $PbTiO_3$ thin film · IR focal plane arrays

1 Introduction

Uncooled infrared (IR) focal plane arrays based on pyroelectric materials can make an IR image system smaller, lighter weight, lower power consuming, higher performance and lower cost. This kind of IR image systems can be used not only for military applications, but also for civil and industrial applications, such as driver's aid, industrial process monitoring, firefighting, portable mine detection, search and rescue, etc. [1–5].

In our previous works, $PbTiO_3$ (PT) thin film IR sensitive arrays of 2×64 and 2×128 elements with a multilayer pyroelectric thin film structure (MPTFS) have been realized. In the MPTFS [6, 7], a porous silica film, used as a thermal insulation layer, is inserted between a pyroelectric thin film and a substrate. The specific detectivity of 9.3×10^{-7} cm·Hz$^{1/2}$/W for a PT thin film element has been obtained [8]. The result suggests that the MPTFS is a promising candidate for applications on uncooled IR focal plane array detectors. However, the value of the specific detectivity is still less than a threshold value of 1.0×10^{-8} cm·Hz$^{1/2}$/W for the practical applications. The properties of the multilayer pyroelectric thin film need to be improved further.

According to the FEA simulated calculation [9, 10], the temperature increment in the pyroelectric layer increases with thickness of the porous silica films. It suggests that the higher specific detectivity may be achieved by adopting a thicker porous silica film. As such, we need to know the relationship between the thickness of porous silica films and the properties of the multilayer pyroelectric thin film. Consequently the thickness of a porous silica film and the IR detectivity can be optimized.

In this paper, the multilayer PT pyroelectric thin film elements with various thicknesses of porous silica films were prepared. The effects of the porous silica film's thickness on the properties of PT thin film IR sensitive elements were studied.

2 Preparation of PT thin film infrared sensitive elements

A <111> silicon wafer with 400 nm thermally oxidized silica was used as substrate. The porous SiO_2 thin films

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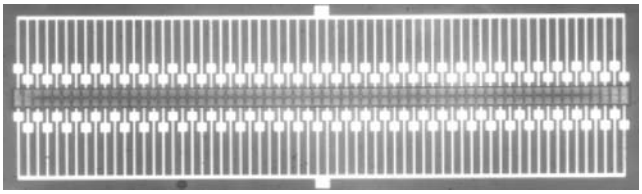

Fig. 1 2×64 PT thin film array with size of 80×80 μm

were prepared on the substrate by a modified sol–gel method. The SiO_2 thin films with thickness of 1–4.5 μm were obtained by repeating a spin-coating and pre-annealing process. A buffer layer with thickness of about 0.5 μm was coated on the porous SiO_2 thin film to improve the surface roughness. Finally the SiO_2 thin films were annealed at temperature of 550 °C for 30 min. The preparation details can be found in [11]. The porosity of the SiO_2 thin films in this study is about 45%.

Pt/Ti bottom and Au top electrodes for the pyroelectric thin film elements were prepared by a DC sputtering method. Ni/Cr IR absorption layer was deposited onto Au top electrode by an evaporation method. Patterning the Pt and Au electrodes as well as Ni/Cr layer was achieved by a conventional lift-off technique used in an IC process. The pyroelectric PT thin films were prepared by a metallo-organic decomposition (MOD) process. PT complex alkoxide precursor was deposited on the Pt/Ti/porous SiO_2/SiO_2/Si substrate, the final films were annealed at the temperature range of 550–650 °C for 1 h. The thickness of PT thin films is 0.6 μm. Micro-patterning of the PT thin films was realized by a wet chemical etching method.

Figure 1 shows a multilayer PT thin film array with 2× 64 elements. The element size is 80×80 μm.

3 Results and discussion

Figure 2 shows a C–V curve of a PT thin film without a porous silica layer. Figures 3, 4 and 5 show C–V curves of PT films with porous silica layers of 2.5, 3.1 and 4.1 μm thick, respectively. For the PT film without the porous silica layer, high bias voltage can be applied. But after adding the porous layers, the maximum bias voltages applied on the PT films decrease with increasing thickness of the porous silica layers. The film samples are broken down when the applied voltages exceed the maximum bias voltages.

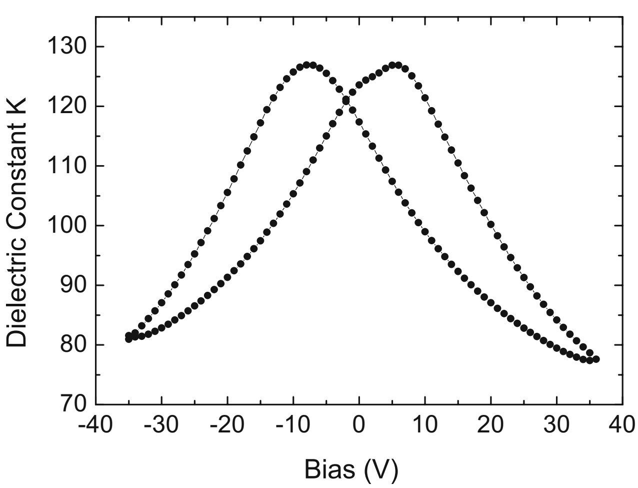

Fig. 2 C–V curve of PT thin film element without a porous silica film

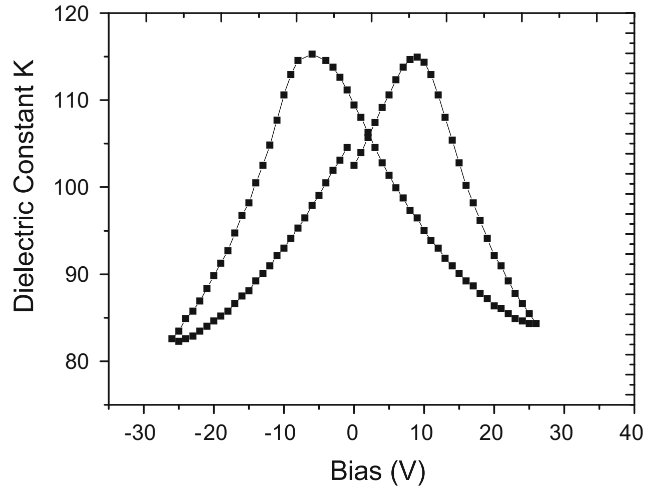

Fig. 3 C–V curve of PT thin film element with a 2.5 μm porous silica film

The dielectric properties of the PT thin film IR sensitive elements with various thicknesses of the porous silica films are listed in Table 1. It can be seen that with increasing thickness of the porous films, the coercive field E_c increases, the dielectric constant ε and breakdown field E_b of the PT thin films decrease. But the loss tangent tgδ does not change obviously. For the film sample without the porous silica layer, the dielectric constant ε, the coercive field E_c and the breakdown field E_b are 123, 108 and 580 kV/cm, respectively. When the thickness of the porous

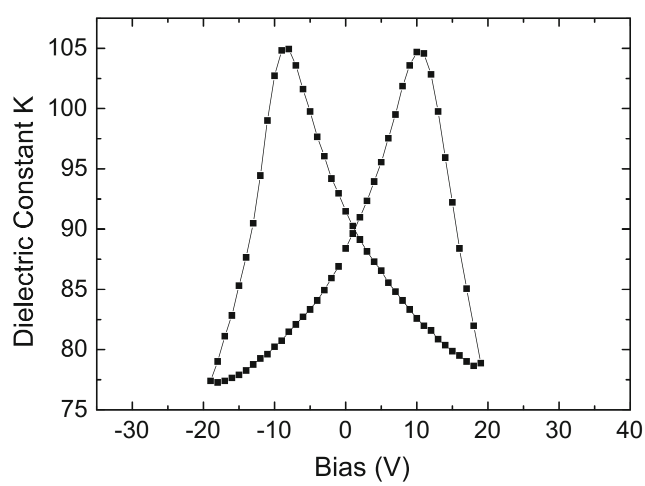

Fig. 4 C–V curve of PT thin film element with a 3.1 μm porous silica film

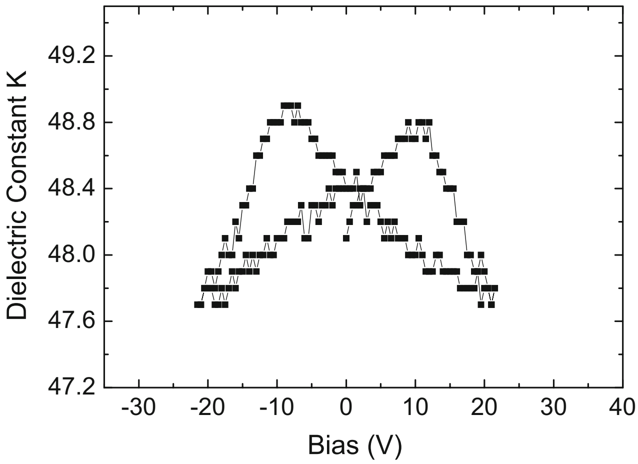

Fig. 5 C–V curve of PT thin film element with a 4.1 μm porous silica film

silica layers is in a range of 1.0 to 2.5 μm, the ε is between 105 and 110, the E_c is between 120–125 kV/cm and the E_b is between 470 and 550 kV/cm. Whereas the ε and E_b decrease sharply when the thickness of porous silica layers reaches to 4.1 μm, the ε and E_b are only 48 and 330 kV/cm.

The change of properties of PT thin films IR sensitive elements may be resulted from a large stress, space charges and defects in the PT thin films induced by the porous silica layers. The stress may pin ferroelectric domains in the PT films. As a result, with the thickness of porous silica films increases, the dielectric constants decrease and coercive field increases, as shown in Table 1. Further study on the stress effect on the properties of MPTF is under way.

According to the above results, to obtain good electrical properties and higher thermal insulating performance of the MPTFS, the optimized thickness of the porous silica films should be chosen in the range of 2–3 μm.

4 Conclusions

Increasing thickness of porous silica films can improve the temperature increment in the pyroelectric layer, but the thickness can not be increase without limit. With increasing thickness of porous silica film in a multilayer pyroelectric thin film structure, the electric properties of PT thin films exhibit a deteriorating trend. In general, the coercive field increases, the dielectric constant and the breakdown field decrease. When the thickness of the porous silica films is lower than 3 μm, the properties of PT thin films are close to that of PT films without porous silica films. To achieve an optimized equilibrium between the electric properties and the thermal insulating performance, the thickness of the porous silica layers should be controlled between 2 and 3 μm.

Table 1 Properties of PT film elements with porous SiO_2 films of various thicknesses.

Samples	Dielectric constant ε (1 kHz)	Loss tangent tgδ (1 kHz)	Coercive field E_c (kV/cm)	Breakdown field E_b (kV/cm)
Without SiO_2	123	0.023	108	583
1.0 μm SiO_2	110	0.018	120	550
2.0 μm SiO_2	106	0.023	130	500
2.5 μm SiO_2	105	0.023	125	470
3.1 μm SiO_2	88	0.040	150	330
4.1 μm SiO_2	48	0.042	154	330

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