A new uncooled infrared detector based on 1D localized island porous silicon photonic crystal array

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A new uncooled infrared detector based on 1D localized island porous silicon photonic crystal was described. In this detector, the 1D porous silicon photonic crystal was fabricated by electrochemical etching technique to achieve the thermal isolation and better reflection for specific infrared at low cost serving as the substrate for uncooled infrared detector. Then a buffer layer of 5000 Å Si_3N_4 was deposited in order to improve the surface morphology of this photonic crystal to obtain a good IR absorber layer for pyroelectric application. The reflective spectrum of the 1D localized island porous silicon photonic crystals after deposited Si_3N_4 layer was measured by Fourier Transform Infrared Spectroscopy (FTIR). The result shown that deposited Si_3N_4 layer on the surface of localized photonic crystalline islands could not change the characteristics of photonic crystal. Subsequently, the sol-gel processing technology was adopted to deposit a thick BST thin film as the sensitivity layer. The detectivity dependence on the chopper frequency, at a bias voltage of 5 V, is 6.2×10^8 cm $Hz^{1/2}/W$, higher than the substrate of Si and porous silicon at the same condition. It has demonstrated that the structure of 1D localized island porous silicon photonic crystal was a promising substrate material for uncooled infrared detectors.

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1. Introduction

During the past decades, the uncooled infrared detectors have became well known that find applications both in civilian and defence utilities such as night vision camera, surveillance and missile guidance due to their advantages such as low cost, low weight, wide spectral response and operated at room temperature. To enhance their responsivity, the sensitive layers must have lower thermal conductance and at the same time higher effective infrared absorbing capacities. Many uncooled infrared detectors have been fabricated using surface micromachining techniques and a bulk micromachining technique [1-3] by anisotropic silicon etching to prevent the heat from dissipating away to the substrate for accomplish a good thermal isolation between the detector structure and substrate, such as using the structure of bridge hung in air, structure of air gap, structure of tiny bridge and more hole layer of SiO_2 [4-7]. Unfortunately, the complex technique, special equipment and the quality as well as stability of the substrate limited their application. In order to improve the infrared absorption, until now, metal/dielectric/metal structure [8] and quarter-wavelength air cavity structure [9] are developed, but it is baffled by the harsh technology, low reproducibility and ununiformity.

Recently, it was reported that the oxidized porous silicon has unique thermal insulation properties, and photonic structures could be fabricated based on porous silicon by periodically alternative etching current form multilayer structures which could reflect specific infrared. Considering a whole structure has not only thermal isolation property but also better reflection for specific infrared, especially, compatibility with the existing complementary metal oxide-semiconductor (CMOS) technology which is vital for facility connected with other electrodevices. In this work, we present a novel 1D localized island photonic crystal array as infrared reflecting substrate for uncooled infrared detectors. This structure has better thermal isolation, higher infrared reflection, better stability and more preferable interconnection between each unit in devices.

2. Experimental details

In this paper, Single-polished p-type <100> silicon with resistivity of 2-8 Ω·cm and the thickness of 525 μm had been employed as substrates. Firstly, Low-stress Si_3N_4 6000 Å was deposited as a mask onto the substrate with low pressure chemical vapor deposition (LPCVD) combined with photolithograph process to obtain island windows for fabricated localized photonic crystal. Secondly, multilayer structure was obtained via periodically alternative electrochemical etching currents in each island. The anodization process was performed in a program controlled electrochemical system. The electrolyte is HF (40%):C_2H_5OH (99%) = 1:1 (by volume). The parameters were adjusted accurately to ensure the current density kept at 10 $mAcm^{-2}$ or 70 $mAcm^{-2}$ to the formation of the low porosity layer or the high porosity layer. Multilayer structures were achieved by alternating the anodization current periodically in the controlling program. Thirdly, the fabricated porous silicon multilayer structure was oxidized in a selective condition at 500℃ for 20 minutes under 0.6 L/min oxygen flux [10] [11] to obtain a stable porous silicon photonic crystal structure. At last, a buffer layer of 5000 Å Si_3N_4 was deposited on the surface of photonic crystal substrate by Plasma Enhanced Chemical Vapor Deposition (PECVD) at 280 ℃ which can not only improve the surface morphology but also obtain a good IR absorber material for pyroelectric application. The optical transmission spectrum of the localized island photonic crystal array was characterized by FTIR.

The sensitive layer of Barium strontium titanate (BST) thin film was formed on this substrate by sol-gel method. The process was conducted as follows.

Barium acetate (Ba $(CH_3COO)_2$), strontium acetate ($C_4H_6O_4Sr$) and Tetrabutyl titanate ($C_{16}H_{36}O_4Ti$) were used as the starting materials for the synthesis of precursors for BST thin film. Barium acetate (0.65 M) and strontium acetate (0.35 M) were first dissolved in glacial acetic acid with continuous stirring and heating. Then Tetrabutyl titanate (1 M) was dissolved in a spot of isopropanol to increase the stability in the same way with a stoichiometric amount of acetylacetone ($C_5H_8O_2$). The above two precursor were mixed under continuous heating and stirring, the pH was maintained at 4-5 by acetic acid glacial. At last a clarity sol solution was obtained. Then the BST sol solution was spin-coated onto the surface of porous silicon photonic crystal at 4000 rpm for 40 s to form wet film. The films were dried at 100℃, the spin-coating and dried processes were repeated until the desired film thickness of approximately 400 nm was achieved. The films were then annealed at 700 ℃ in a rapid thermal processor (RTP).

The thin film crystal structure was examined using X-ray diffraction (XRD) with CuKα radiation. The detectivity of the prototype model was obtained dependence on the chopper frequency, at a bias voltage of 5 V.

3. Results and discussion

Fig.1 depicts the fabrication process of the designed model, which consists of top electrode, bottom electrode, detecting element, and the substrate of localized island photonic crystal. The Ti and Pt layers with 100 nm and 200 nm, respectively, were orderly deposited on the top of the localized island photonic crystal after being evaporated 5000 Å Si_3N_4 as the transition layers. Then the sol-gel processing technology was adopted to deposit 500 nm thick BST thin film on the surface of Pt as the sensitivity layer. At last, a 200 nm thick platinum layer was evaporated as the top electrode.

Fig.2 shows the black-scattered electron SEM image of localized island photonic crystal. In this picture, the whole structure was shown clearly. From the top-down picture (Fig.2 (a)), we can see that on the surface of silicon there are many circle windows which are well isolated and paralleled to one another. It was evidently seen that lateral etching exists obviously under the silicon nitride mask apart from the part of the opening window on the silicon. Although the surface appears obvious grooves, the brim of the patterned sample surface was very clear, and the Si_3N_4 masking layer keeps intact. From the cross-section image (Fig.2 (b)), it was clearly, in the light-grey areas, that porous silicon photonic crystal was formed selectively and regularly which appear columnar and directional. High (dark) and low (bright) porosity layers were absolutely distributed. It is more clearly that there exist seriously lateral etching too, and the growth rate of etching in perpendicular is always bigger than that of the etching in profile.

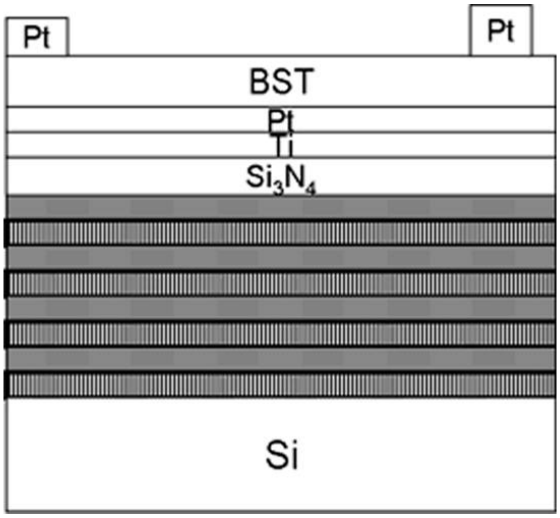

Fig.1 The fabrication process of the designed uncooled infrared detector prototype.

The reflectivity of the localized photonic crystalline islands before (a) and after (b) deposited 5000 Å Si_3N_4 was tested using FTIR. As shown in Fig.3, the reflectance spectroscopies before and after deposited Si_3N_4 layer are all have better reflectivity in the spectral region between 10 μm and 14 μm. The mid-gaps lie in λ =12 μm. The photonic band gap widths are about 4 μm. The band gap was broaden after deposited Si_3N_4 layer .The results shown that deposited Si_3N_4 layer on the surface of localized photonic crystalline islands could not change the characteristics of photonic crystal, and it could improve the surface morphology for obtaining a good IR absorber material. The dip in the spectra was associated with the absorption band of Si-N [12-16].

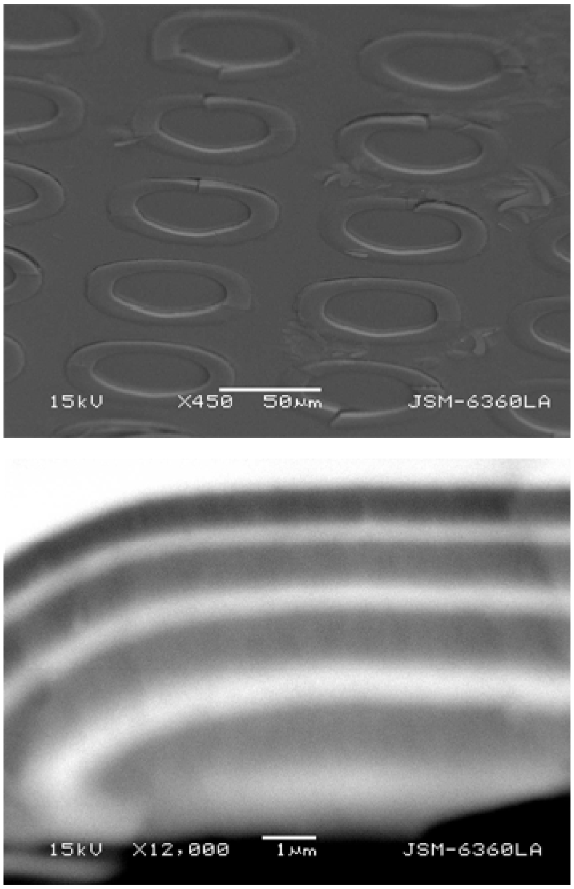

Fig.2 The black-scattered electron SEM image (a) and the cross-sectional SEM image (b) of the localized photonic crystal.

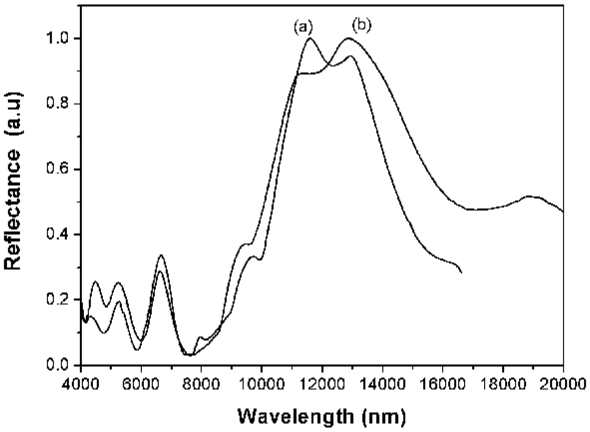

Fig.3 Optical reflectance spectra of the Si_3N_4 layer before (a) and after (b) deposited on the surface of the localized photonic crystalline islands.

The X-ray diffraction patterns of the BST thin film deposited on localized island photonic crystal substrate was shown in Fig.4. It is seen that the BST film had randomly oriented pure pervoskite structure.

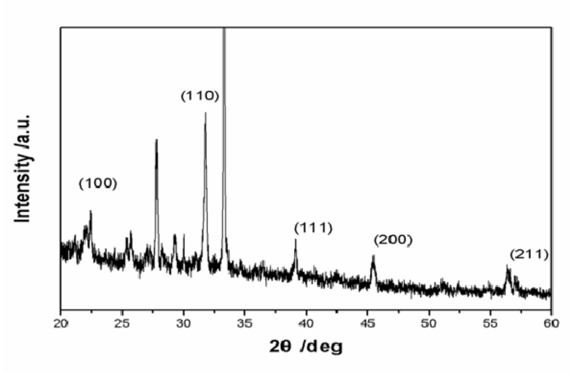

Fig.4 The X-ray diffraction patterns of the BST thin film deposited on localized photonic crystalline islands substrate.

In order to study the substrate influence on the performance of the uncooled infrared detector, three different substrates (Si, porous silicon, localized photonic crystalline islands) were adopted in this experiment. The detectivity dependence on the chopper frequency, at a bias voltage of 5 V, were 1.2×10^{8} cm $Hz^{1/2}/W$, 3.7×10^{8} cm $Hz^{1/2}/W$, and 6.2×10^{8} cm $Hz^{1/2}/W$, respectively. So it is clearly that our proposed uncooled infrared detector prototype based on the localized island photonic crystal has the best detectivity.

4. Conclusion

In summary, an uncooled infrared detector prototype based on the localized island porous silicon photonic crystal was successfully fabricated. The substrate of localized island porous silicon photonic crystal was formed by electrochemical method, which was not only an absolute heat layer but also a highly reflective layer. In order to compare, silicon and porous silicon were chosen as the substrate too. The BST thin film with better crystalline structure was formed on this substrate by sol-gel method. The results of the detectivity indicated that the uncooled infrared detector with localized island porous silicon photonic crystal substrate had better performance than others. The experiment results show that the multilayer thin film was a promising choice for developing high performance pyroelectric infrared detectors.

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