High performance THz detector based on ultra-thin $LiTaO_3$ crystal

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Abstract—**Research on high performance terahertz (THz) detector is essential for promoting the application of THz science and technology. Lithium tantalate crystal ($LiTaO_3$) was used to fabricate the THz detector in this paper. Polishing process were used to reduce the thickness of $LiTaO_3$ crystal slice obtained the area of 2mm×2mm×10μm $LiTaO_3$ wafer pyroelectric coefficient of $4.7\times10^{-4}Cm^{-2}K^{-1}$ by chemical mechanical polishing techniques. The THz responsivity for detector tested by lock in amplifier reaches $8.38\times10^{4}V/W$ and the lowest noise equivalent power value(NEP) reaches $3.25\times10^{-12}W$ at 20Hz operating frequency use 2.52THz radiation, which is suitable for THz imaging application. Meanwhile it provides a feasible approach for fabricating high responsivity THz detector.**

I. INTRODUCTION

The terahertz (THz) region of electromagnetic spectrum is often described as the final unexplored area of spectrum.

THz radiation due to its unique properties provides a variety of applications and opportunities in different field. It is one of emerging technologies that will change our life. A lot of attractive applications in security, medicine, biology, astronomy, and non−destructive materials testing have been demonstrated already. However, the realization of THz emitters and receivers is a challenge because the frequencies are too high for conventional electronics and the photon energies are too small for classical optics. Therefore, the detection of THz radiation is resistant to the commonly employed technique in the neighbouring microwave and infrared frequency bands[1].

Metal blacks were first discovered to be good absorbers of IR radiation by Pfund in the 1930's[2,3]. Similar black films based on gold and other metals were investigated extensively by Harris and others in the 1950's and 1960's[4-7].The THz characteristics of thin metal films is attractive for security and medical applications due to its ability to penetrate most dry, non–polar materials without damaging them[8,9]. Metallic films for terahertz(THz) absorption have been shown to be usable as an effective detection system for infrared radiation[10]. In THz detector based on ultra-thin $LiTaO_3$ crystal, the absorbed energy heats the sensing element, changing its polarization and producing an output proportional to the incident optical power[11]. However the detector provide a low sensitivity at THz frequencies due to poor absorption of THz radiation[10]. To increase sensitivity, it is necessary to design a pixel membrane absorption structure to efficiently absorb THz radiation without compromising the thermal proprieties of the detectors. In this paper goldblack thin films which act as THz absorption layers are deposited on the lithium tantalite crystal.

II. RESULTS

The typical THz detectors based on ultra-thin $LiTaO_3$ crystal is a device structure with $LiTaO_3$ material sandwiched between two metal electrodes. It belongs to thermal detectors. In a thermal detector, the incident radiation is absorbed to change the material temperature, and the resultant change in some physical property is used to generate an electrical output. The detector is suspended on lags, which are connected to the heat sink. The signal does not depend upon the photonic nature of the incident radiation. Thus, thermal effects are generally wavelength independent[1], the signal depends upon the radiant power (or its rate of change) but not upon its spectral content. Since the radiation can be absorbed in a black surface coating, the spectral response can be very broad. To enhance the absorption in THz region, a thin-film THz absorber structures for thermal detectors is covered on the top $LiTaO_3$ crystal surface by special method. Because the terahertz detector is a kind of thermal sensitive detector, the heat conduction of the device needs to be considered. The structure of THz crystal detector, from top to bottom, is THz goldblack absorb coating/dielectric layer/ferrite layer/ goldblack absorb coating/$LiTaO_3$ crystal (2mm×2mm thickness 10μm)/ goldblack reflector layer. It is an effective way to improve the performance of THz detector based on $LiTaO_3$ crystal with high response and the lowest noise equivalent power value (NEP). Goldblack films were deposited on the lithium tantalite crystal of THz detector by magnetron sputtering.Films with 10nm thicknesses was prepared.

The biggest challenge in implementing THz detector based on $LiTaO_3$ is high fragile, which is particularly intrinsic to ultra-thin (10μm) $LiTaO_3$ wafer. In all previous implementations of the pyroelectric Thz radiation with optical readout, the incident Thz radiation goes through the solid Si substrate. This imposes several limitations on the detector performance. The most significant limitation is related to thermal dissipation.We propose to surmount this limitation by removing the substrate material underneath the absorbing area of Thz detector. In addition to providing an unobstructed optical path for THz radiation,this design eliminates the shortest pathway for heat transfer between the absorber and the substrate. Therefore, the thermal isolation of the detector can be improved.

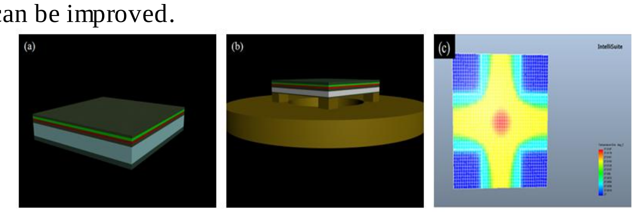
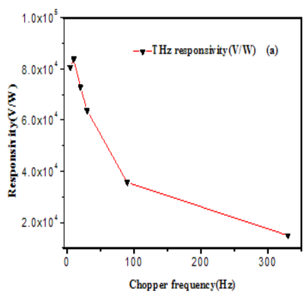


Fig.1Three dimension device structures and temperature changing map at fixed energy flux of THz detector(a) absorption layer structures,(b)device structures with $LiTaO_3$ crystal slice, (c) simulation result of the temperature changing of the THz detector.

The Thz detector can be considered as a small capacitor with two conducting electrodes mounted perpendicularly to the direction of spontaneous polarization. During incident radiation, the change in polarization appears as a charge on the capacitor and a current is generated, the magnitude of which depends on the temperature rise and the pyroelectric coefficient of the $LiTaO_3$ crystal material. The signal must be chopped or modulated. The detector sensitivity is limited either by amplifier noise or by loss−tangent noise. Response speed can be engineered making Thz detectors useful for fast laser pulse detection, however with proportional decrease in sensitivity.

The Thz detector fabricated with the ultra-thin (10μm) LT crystal and device structure as shown in Fig. 1(a) and (b). from top to bottom is THz goldblack absorb coating/ dielectric layer/ferrite layer/goldblack absorb coating/ $LiTaO_3$ crystal/ goldblack reflector layer. When a heat flux of $4.7\times10^{-11}W/\mu m^2$ is applied on the detectors, the temperature map of the devices is shown in Fig.1(c). It's obvious the temperature increasing value of device structure and the temperature uniformity is good. It is an effective way to improve the performance of THz detector based on ultra-thin $LiTaO_3$ crystal.



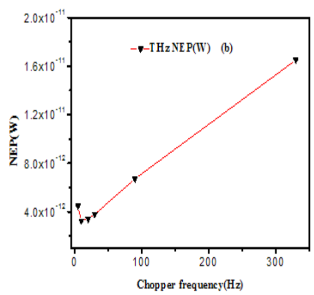


Fig. 2 Responsivity, NEP parameters of THz detector at at 2.52 THz with a goldblack thickness of 10nm, (a)responsivity parameter, (b)NEP parameter.

Because the detector is a direct detection detector, 2.52THz laser radiation acted as radiation source. The detecting frequency could be controlled precisely by chopper. The response voltage (*Vs*) signal and the noise voltage (*Vn*) of Thz detector shown in Fig.2 were measured with lock in amplifier (SR850) at room temperature after removing ambient radiation. The responsivity for THz detector tested by lock in amplifier reaches 8.38×10^4 V/W and the lowest noise equivalent power value(NEP) reaches 3.25×10^{-12}W at 20Hz operating frequency use 2.52THz radiation.

III. SUMMARY

The feasibility of preparing a high responsivity THz detector based on lithium tantalate crystal ($LiTaO_3$) in this paper. Polishing process were used to reduce the thickness of $LiTaO_3$ crystal slice obtained the area of 2mm×2mm×10μm $LiTaO_3$ wafer pyroelectric coefficient of $4.7\times10^{-4}Cm^{-2}K^{-1}$ by chemical mechanical polishing techniques. Goldblack metallic films for absorption of THz was evident.The THz responsivity for detector tested by lock in amplifier reaches 8.38×10^4 V/W and the lowest noise equivalent power value(NEP) reaches 3.25×10^{-12}W at 20Hz operating frequency use 2.52THz radiation, which is suitable for THz imaging application. Meanwhile it provides a feasible approach for fabricating high responsivity THz detector.

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