Terahertz absorption characteristics of nickel–chromium film in a microbolometer focal plane array

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Published in Micro & Nano Letters; Received on 24th December 2013; Revised on 20th February 2014; Accepted on 3rd March 2014

Nickel–chromium (NiCr) thin film acted as a terahertz (THz) absorption layer in uncooled infrared (IR) microbolometers operated in the THz spectral range. Nanoscale NiCr thin films with different thicknesses were deposited on the diaphragms of 320 × 240 IR focal plane arrays (IRFPAs). The experiments suggested that the THz absorption of NiCr film increased with the increased frequency. Absorption for a lower frequency decreased whereas that for a higher frequency increased with the decreased film thickness. Optimised absorption for different spectral ranges was achieved by adjusting the NiCr film thickness. A 30 nm NiCr film provided the largest absorption in 0.5–1.5 THz whereas an 8 nm NiCr film showed the greatest contribution in 2–2.5 THz. The THz absorption characteristics of the pixel membrane structure in the IRFPAs coupled with a thin metallic film were modelled and analysed. A good agreement was obtained between the calculations and the measurements.

1. Introduction: Imaging with terahertz (THz) radiation has shown its value in many areas, such as security and medical applications, because of its low power of emitted photons and non-ionising nature [1–3]. THz imaging has been demonstrated by using conventional uncooled microbolometer infrared focal plane arrays (IRFPAs) optimised for infrared (IR) radiation (8–12 μm) coupled with an external THz illumination source [4–6]. A potential limitation of this approach is that the low sensitivity for the conventional microbolometer arrays provide a low absorption ratio of 2.6–4% in the THz spectral range [7, 8]. One option for improving the absorption is to integrate an absorption layer which efficiently absorbs the THz radiation [9]. Metamaterial absorbers with a nearly 100% absorption have been designed and fabricated by using a periodic array of aluminium (Al) squares and an Al ground plane separated by a thin silicon dioxide (SiO_2) dielectric film [10–12]. However, the metamaterial absorbers can hardly be integrated in the microbolometer IRFPAs. Nanoscale metallic film deposited on a dielectric layer is known to provide good THz absorption because of resistive loss in the film [13]. The THz characteristics of thin metal film have been modelled and it is predicted that a maximum absorption of 50% can be achieved ideally [10]. Nickel–chromium (NiCr) film is suitable for a THz absorption layer because of its small heat capacity and high resistivity. Furthermore, its preparation and patterning processes are compatible with the microfabrication process of the microbolometer IRFPAs.

In this Letter, NiCr thin films were deposited on the diaphragms of the 320 × 240 IRFPAs. Absorptions of the diaphragms with different NiCr thicknesses were reported. The THz absorption characteristics of the pixel membrane structure coupled with a thin metallic film were also modelled and analysed.

2. Experimental: A pixel structure of 320 × 240 IRFPAs fabricated with a pitch of 37 μm is shown in Fig. 1. Each pixel consists of a diaphragm (sensitive area), a cell contact and two legs which support the diaphragm. The diaphragm is composed of a vanadium oxide (VO_x) thin film upon a silicon nitride (Si_3N_4) air bridge, with a reflection layer placed $\sim\lambda/4$ away ($\lambda = 10$ μm) for a resonant absorption of the IR radiation. The resonant chamber only functions as a heat isolation structure in the THz wave band because of the expanded wavelength. To improve the THz absorption, nanoscale NiCr (Ni:Cr = 80:20) films were deposited on the diaphragms by the reactive sputtering of a high purity NiCr target in an Ar atmosphere. NiCr films with different thicknesses from 8 to 36 nm were prepared.

Since transmission was negligible because of the reflection layer, absorption of the samples, $A(\lambda)$, was calculated by using $A(\lambda) = 100\%–R(\lambda)$. The reflection, $R(\lambda)$, was measured by a THz time-domain spectroscopy (THz-TDS) system with an incident direction of 30°.

3. Results and discussion: The THz absorptions of the diaphragms in the 0.5–1.5 THz spectral range with different NiCr thicknesses are shown in Fig. 2. They suggest that the NiCr thin film acts as a THz absorption layer in the pixel membrane structures. NiCr film with a thickness of 30 nm provides the largest absorption whereas the 8 nm NiCr film shows the smallest contribution in this spectral range. The absorption of the NiCr film with a thickness of 30 nm is higher than that of the film with the thicknesses of 20 and 36 nm, respectively. It seems that at a certain frequency in the 0.5–1.5 THz range, the THz absorption of the NiCr film increases with increase of the film thickness to its largest at 30 nm, and then decreases when the film is thicker than 30 nm.

As shown in Fig. 2, the THz absorption of the NiCr film with a certain thickness increases with the increased frequency. An 8 nm NiCr film has the most significant increase in the higher frequency range. This can be demonstrated by Fig. 3, which shows the THz absorptions of the diaphragms in 0.5–2.55 THz with NiCr film thicknesses of 8 and 20 nm, respectively. In the higher frequency range, the 8 nm NiCr film provides a higher absorption compared with the NiCr film with a thickness of 20 nm. The curves indicate that an absorption of about 25 and 15% are obtained in the spectral range of 2.2–2.5 THz for the 8 and the 20 nm NiCr films, respectively. It becomes clear that the THz absorption for the lower frequency decreases whereas that for the higher frequency increases with the decrease of the NiCr film thickness. This means that the largest absorption for the higher frequency is obtained by the NiCr film with a smaller thickness. Optimised absorption at different spectral ranges can be achieved by controlling the thickness of the NiCr film.

To understand the absorption of a metallic film in the IRFPAs, the THz absorption characteristics of the pixel membrane structure coupled with a thin metallic film are modelled and analysed below. Here, a simplified structure (see Fig. 4) is taken and the NiCr film is

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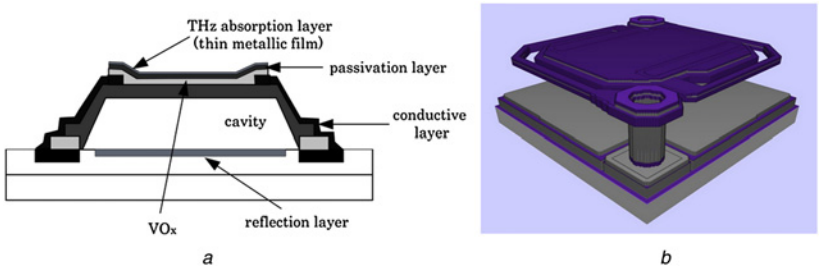


Figure 1 *Schematic cross-sectional view*
a Structural representation
b Pixel structure in the 320 × 240 IRFPAs

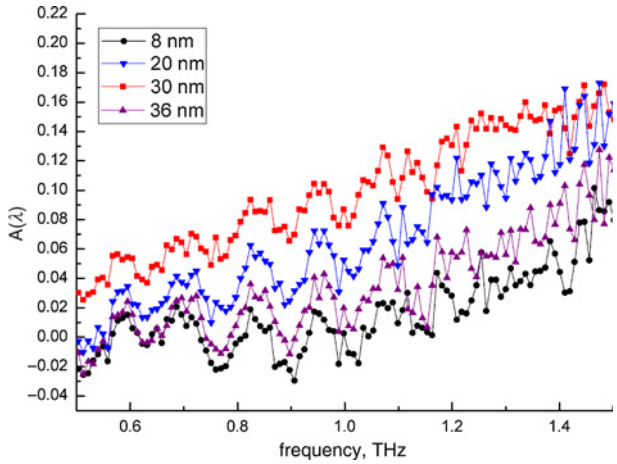


Figure 2 *THz absorptions of the diaphragms in the 0.5–1.5 THz spectral range with different NiCr thicknesses (8, 20, 30 and 36 nm, respectively)*

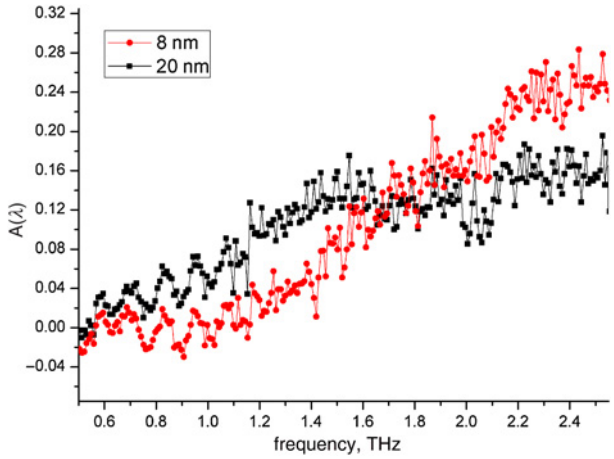


Figure 3 *THz absorptions of the diaphragms in the 0.5–2.55 THz spectral range with NiCr thicknesses of 8 and 20 nm, respectively*

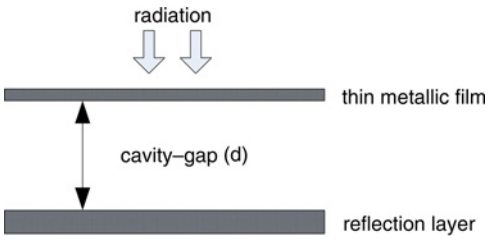


Figure 4 *Simplified optical resonance cavity of the pixel membrane structure coupled with a thin metallic film*

adopted as the metallic absorption layer. Based on the formula of Liddiard [7, 14], the absorption of the diaphragms, $A(\lambda)$ can be expressed as follows

$$A(\lambda) = \frac{4}{Dn^2}\left\{\left[f_s(f_r+1)^2/n^2 + f_r\right]\sin^2\theta + (f_r+f_s)\cos^2\theta\right\}$$

where

$$D = \left[(f_r+1)(f_s+1)/n^2+1\right]^2\sin^2\theta + \left[(f_r+f_s+2)^2/n^2\right]\cos^2\theta$$
$$f_r = 120\pi/R_r$$
$$f_s = 120\pi/R_s$$
$$\theta = 2\pi nd/\lambda$$

Here λ is the wavelength, θ is the phase shift occurring when the radiation which travels in a vertical direction passes through the cavity-gap, n is the refractive index of the cavity, d is the cavity-gap width, R_r is the sheet resistance of the reflection layer and R_s is the sheet resistance of the NiCr absorption film, respectively.

Fig. 5 shows the calculated relationship of the THz absorption to the sheet resistance of the NiCr film at four frequencies for $n = 1$, $d = 2.5$ μm and $R_r = 5\ \Omega/\square$, respectively. It can be seen that the NiCr film with different sheet resistances provides the largest absorption at different frequencies. The sheet resistance of the NiCr film optimised for the largest absorption increases and the thickness of the NiCr film decreases with the increased frequency because of the inverse relationship between the sheet resistance and the film thickness ($R_s = \rho/d_s$). For the NiCr film with a certain sheet resistance and thickness, the THz absorption increases with the increased frequency. This is demonstrated by measurements in both Figs. 2

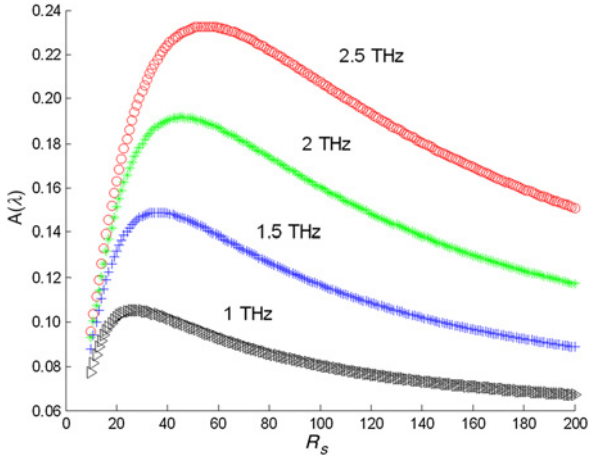


Figure 5 *Relationship of the THz absorption with the sheet resistance of the NiCr film for four frequencies (1, 1.5, 2 and 2.5 THz, respectively)*

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doi: 10.1049/mnl.2013.0711

and 3. The calculations show a good agreement with the measurements.

4. Conclusions: Nanoscale NiCr films which acted as THz absorption layers with varying thicknesses were deposited on the diaphragms of the 320×240 VO_x-based IRFPAs. For the NiCr film with a certain sheet resistance and thickness, the THz absorption increased with the increase of the frequency. The thickness of the NiCr film decreased with the increased frequency for the largest absorption. Optimised absorption for different spectral ranges was achieved by adjusting the NiCr film thickness. NiCr film with a thickness of 30 nm provided the largest absorption in the spectral range of 0.5–1.5 THz. An absorption of 25% was obtained in the 2.2–2.5 THz range for the NiCr film with a thickness of 8 nm. Optimised absorption for a higher frequency was obtained by the NiCr film with a smaller thickness. The THz absorption characteristics of the pixel membrane structure coupled with a thin metallic film were modelled and analysed, which agreed well with the measurements.

5. Acknowledgments: This work was supported by the National Natural Science Foundation of China (grant nos 61235006, 61006036 and 61101030) and the New Century Excellent Talents in University (NCET-10-0299).

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