Preparation of Nanostructured NiCr Film as a Terahertz Absorption Layer by Magnetron Sputtering and RIE

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***Abstract*—Nanostructured NiCr thin film was prepared by a combination of magnetron sputtering and reactive ion etching (RIE) in 80 × 60 uncooled infrared focal plane arrays (IRFPA). The surface morphologies and THz absorption characteristics of the IRFPAs were tested with NiCr absorption layers prepared by magnetron sputtering and the combined process respectively. The tests suggested that THz absorption could be effectively enhanced by RIE processes applied to the dielectric substrate and NiCr film, which increased the specific surface area of NiCr absorption film by generating nano – scale structures on upper and lower surfaces.**

I. INTRODUCTION

Imaging with terahertz (THz) radiation is attractive for applications in many areas such as security and medical due to its low power of emitted photons and non-ionizing nature [1~3]. Conventional uncooled infrared focal plane arrays (IRFPA) coupled with an external terahertz (THz) illumination source have been proved to be an effective THz imaging system [4~6]. However, due to poor absorption of THz radiation, uncooled IR microbolometers generally have a very low noise equivalent power (NEP) in the THz range compared to NEP for the IR range, which implies low responsivity at THz frequencies [7~8]. The absorption can be improved by creating black metal [9] or producing metamaterial structures, but it can hardly be integrated in the microbolometers [10]. A commonly used approach is to integrate a thin metallic film to absorb THz radiation due to resistive loss in the film[11~12].

In our earlier research, we have reported THz absorption characteristics of nickel – chromium (NiCr) film in microbolometer-based IRFPAs [13]. NiCr thin film has been proved to be a good THz absorption layer due to many advantages, such as low heat capacity, high resistivity, good stability and processing compatibility. In this paper, NiCr films were prepared in 80 × 60 IRFPAs by magnetron sputtering, and a combination of magnetron sputtering and reactive ion etching (RIE), respectively. The surface morphologies and THz absorption characteristics of the films were tested and analyzed.

II. RESULTS

THz absorption layers were prepared on micro bridge structures of 80 × 60 IRFPAs with 75 μm pitch pixels. Each pixel consisted of diaphragm (sensitive area), cell contact and two legs which supported the diaphragm. The diaphragm was composed of a vanadium oxide (VO_x) thin film upon a silicon nitride air bridge, with a reflection layer placed ~ λ/4 away (λ = 10 μm) to realize resonant absorption of IR radiation. Over ten photomask patterns were designed to fabricate 80 × 60 IRFPAs with microbridge structures. First of all, bottom electrode metal layer (NiCr thin film, 250 nm thickness), which acted as the bottom electrode and reflection layer, was fabricated on silicon wafer by direct current magnetron sputtering. Photo sensitive polyimide was prepared on the reflection layer as the sacrificial layer by spin coating with a thickness of 2.5 μm. VO_x thermal sensitive thin film was prepared with a temperature coefficient of resistance (TCR) of ~2.3 %/K and a film thickness of 50 nm by direct current magnetron sputtering for a sputter power of 300W, a partial pressure of oxygen of 0.5%, and an annealing temperature of 350 °C at vacuum environment. The dielectric passivation layer and top metal film (THz wave absorber) were then fabricated on VO_x film by two methods. In the first method, NiCr film with a thickness of 20 nm was directly deposited on 100 nm SiN_x substrate by magnetron sputtering. In the second method, SiN_x film with a thickness of 150 nm was deposited. 50 nm SiN_x film was etched by RIE using CHF_3 and O_2 for a RF power of 400 W, a pressure of 4 Pa, a CHF_3 flow of 20 sccm, and an O_2 flow of 3 sccm. NiCr film with a thickness of 30 nm was deposited on the RIE treated SiN_x substrate and thinned to 20 nm by RIE using a gas mixture of BCl_3, Cl_2 and SF_6 with the same parameters as mentioned earlier. After etching the top membrane using reactive ion etching system, the sacrificial layers could be released completely by oxygen plasma at 280 °C to form suspended micro-bridge structures.

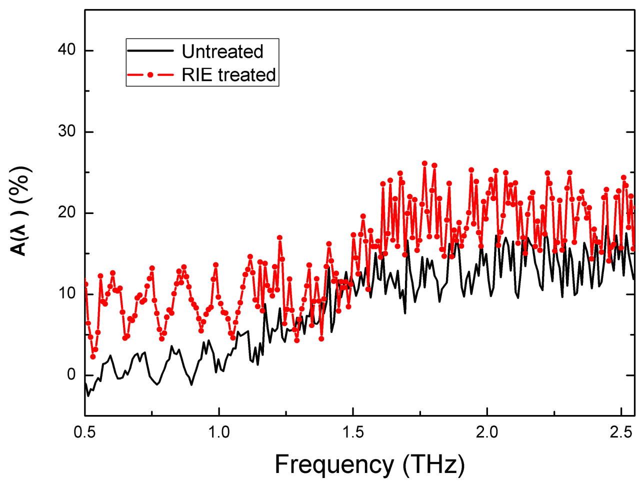

Fig. 1. Absorption characteristics of 80 × 60 IRFPAs with untreated (line without symbol) and RIE treated (line with symbol) NiCr absorption layer

Since transmittance was negligible due to the reflection layer in IRFPAs, absorption was calculated using $A = 100\% - R$. The reflection (R) was measured by a THz time – domain spectroscopy system with an incident direction of 30 degree from the normal direction. Absorption characteristics of 80 × 60 IRFPAs with THz absorption layer prepared by two methods are shown in Fig. 1. An effectively enhanced absorption is observed after RIE treatment in the second method.

AFM images of dielectric substrates and NiCr films in Fig. 2 shows that roughened substrate surface was induced by RIE.

Specific surface area of NiCr film was increased due to nano – scale surface structures. It becomes clear that the effective surface area of NiCr film can be increased due to nano – scale structures.

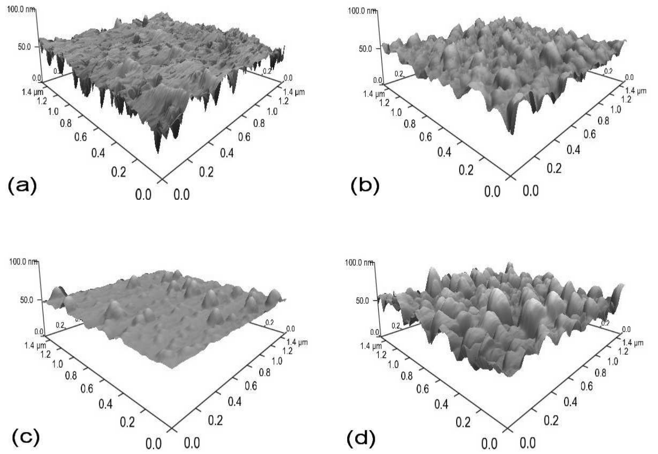

Fig. 2. AFM images of (a) untreated SiO_2 film, (b) RIE treated SiO_2 film, (c) NiCr film on untreated SiO_2 film, and (d) NiCr film on RIE untreated SiO_2 film

Fig. 3 shows the AFM images of NiCr films deposited on untreated dielectric substrates by two methods. It can be seen that the surface of NiCr film directly deposited by magnetron sputtering was very smooth while that of NiCr film thinned by RIE was roughened.

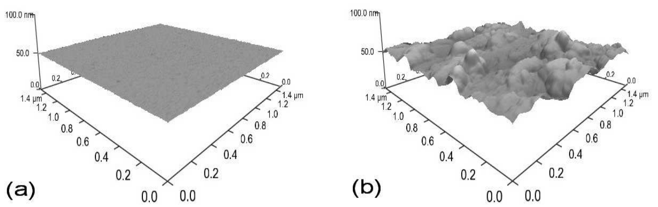

Fig. 3. SEM images of NiCr films deposited by (a) magnetron sputtering and (b) a combination of magnetron sputtering and RIE

It becomes clear that the upper and lower surfaces of NiCr film were both roughened due to nano – scale structures generated by RIE treatment, which contributed to the enhancement of THz absorption. It is known that the absorption, $A(\lambda)$, of a metal film consists of two components [14]: $A(\lambda)=A_{INTR}(\lambda)+A_{SS}(\lambda)$, where $A_{INTR}(\lambda)$ is the intrinsic absorption of an ideally smooth surface and $A_{SS}(\lambda)$ is the contribution due to nano – scale surface structures, which are induced by RIE in this paper.

SEM image of single pixel in 80 × 60 IRFPAs in Fig. 4 shows that NiCr film acted as a black metallic absorption layer in the micro bridge structure.

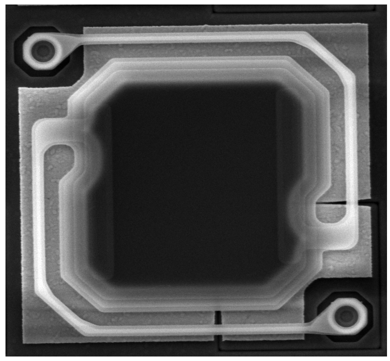

Fig. 4. SEM image of single pixel in 80 × 60 IRFPAs

III. Summary

THz absorption characteristics of 80×60 IRFPAs coupled with a NiCr film were measured and analyzed. A combined process of magnetron sputtering and RIE was adopted to prepare nanostructured NiCr film for enhanced THz absorption. The upper and lower surfaces of NiCr film were both roughened by RIE, which increased the specific surface area of NiCr film due to nano – scale surface structures.

References

[1] J.F. Federici, B. Schulkin, F. Huang, D. Gary, R. Barat, F. Oliveira, and D. Zimdars, "THz imaging and sensing for security applications—explosives, weapons and drugs," *Semicond. Sci. Technol.*, vol. 20, pp. S266–S280, 2005.

[2] S.M. Kim, F. Hatami, J.S. Harris, A.W. Kurian, J. Ford, D. King, G. Scalari, M. Giovannini, N. Hoyler, J. Faist, and G. Harris, "Biomedical terahertz imaging with a quantum cascade laser," *Appl. Phys. Lett.*, vol. 88, pp. 153903-1–153903-3, 2006.

[3] M.A. Dem'yanenko, D.G. Esaev, V.N Ovsyuk, and B.I. Fomin, "Microbolometer detector arrays for the infrared and terahertz ranges," *J. Opt. Technol.*, vol. 76, pp. 739–743, 2009.

[4] A.W.M. Lee, B.S. Williams, Q. Hu, and J.L. Reno, "Real-time imaging using a 4.3-THz quantum cascade laser and a 320×240 microbolometer focal-plane array," *IEEE Photon. Tech. Lett.*, vol. 18, pp. 1415–1417, 2006.

[5] B.N. Behnken, G. Karunasiri, D.R. Chamberlin, et al.: "Real-time imaging using a 2.8 THz quantum cascade laser and uncooled infrared microbolometer camera," *Opt. Lett.*, vol. 33, pp. 440–442, 2008.

[6] B.N. Behnken, M. Lowe, G. Karunasiri, et al.: "Detection of 3.4 THz radiation from a quantum cascade laser using a microbolometer infrared camera," *Proc. SPIE*, vol. 6549, pp. 65490C-1–65490C-7, 2007.

[7] M.J. Coppinger, N.A. Sustersic, J. Kolodzey, and T.H. Allik, "Sensitivity of a vanadium oxide uncooled microbolometer array for terahertz imaging," *Opt. Eng.* , vol. 50, pp. 053206-1–053206-5, 2011.

[8] B. Kearney, F. Alves, D. Grbovic, G. Karunasiri, "Tunable THz absorption using Al/SiO_x planar periodic structures," *Proc. SPIE*, vol. 8363, pp. 836309-1–836309-6, 2012.

[9] A.Y. Vorobyev, C. Guo, "Colorizing metals with femtosecond laser pulses," *Appl. Phys. Lett.*, vol. 92, pp. 041914-1–041914-3, 2008.

[10] Q.Y. Wen, H.W.Zhang, Y.S.Xie, Q.H. Yang, Y.L. Liu, "Dual band terahertz metamaterial absorber: design, fabrication, and characterization," *Appl. Phys. Lett.*, vol. 95, pp. 241111-1–241111-3, 2009.

[11] F. Alves, A. Karamitros, D. Grbovic, B. Kearney, and G. Karunasiri, "Highly absorbing nano-scale metal films for terahertz applications," *Opt. Eng.*, vol. 51, pp. 063801-1–063801-6, 2012.

[12] C. Bolakis, D. Grbovic, N.V. Lavrik, G. Karunasiri, "Design and characterization of terahertz- absorbing nano-laminates of dielectric and metal thin films," *Opt. Express*, vol.18, pp. 14488–14495, 2010.

[13] J. Gou, Y. Jiang, J. Wang, "Terahertz absorption characteristics of NiCr film in a microbolometer focal plane array," *Micro Nano Lett.*, vol. 9, pp. 215–217, 2014.

[14] A.Y. Vorobyev, A.N. Topkov, O.V. Gurin, V.A. Svich, C.L. Guo, "Enhanced absorption of metals over ultrabroad electromagnetic spectrum," *Appl. Phys. Lett.*, vol.95, pp. 121106-1–121106-3, 2009.