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Influence of Reactive Ion Etching on THz Transmission and Reflection Properties of NiCr Film Deposited on a Dielectric Substrate

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Enhanced terahertz (THz) absorption of NiCr film deposited on a dielectric substrate has been proven by applying a reactive ion etching (RIE) treatment to the dielectric film. Nano-scale nickel-chromium (NiCr) thin films are deposited on RIE treated silicon dioxide (SiO_2) dielectric substrates to study the transmission and reflection characteristics. Experimental results suggest that both transmission and reflection of NiCr film are weakened by the RIE treatment. The most significant decrease of transmission is observed in (1 ~ 4) THz while that of reflection occurs in (1.7 ~ 2.5) THz band. The decrease of both transmission and reflection is more significant for NiCr film with higher thickness. The RIE treatment, which induces a roughened surface of SiO_2 substrate and increases the effective surface area of NiCr film, enhances the absorption and weakens the transmission and reflection of THz radiation.

Keywords: NiCr thin film, RIE, THz, transmission, reflection, absorption.

1. INTRODUCTION

Collection of terahertz (THz) radiation is crucial because of its wide variety of applications in molecular spectroscopy, sensing, disease diagnostics, and biomedical imaging [1 – 3]. Metals are virtually perfect reflectors for THz radiation while metallic films have obvious transmission and absorption effects since the film thickness is much smaller than the skin depth of electromagnetic waves [4]. Recently, there is a widespread concern over nano-scale metallic film deposited on dielectric layer, which provides good THz absorption characteristics due to resistive loss in the film [5 – 6]. The absorption of metal film can be further improved by creating the so-called black metal [7] or producing absorbing structures (metamaterial film) [8 – 9]. A thin-film stack containing a dielectric Bragg reflector and a thin chromium metal film, has also been fabricated to absorb 20 % of incident THz power in (3 ~ 5) THz [10]. We have suggested an effective way in [11] to enhance THz absorption of nickel-chromium (NiCr) thin film in microbolometer infrared focal plane arrays (IRFPA) by applying a reactive ion etching (RIE) process to the dielectric support layer. However, the influence of RIE on THz transmission and reflection properties of NiCr film is still unclear.

In this paper, NiCr films are deposited on untreated and RIE treated silicon dioxide (SiO_2) dielectric substrates with different thicknesses. THz transmission and reflection characteristics of the films are reported.

2. EXPERIMENTAL

SiO_2 thin films were deposited from SiH_4/N_2O by plasma enhanced chemical vapor deposition (PECVD) at a temperature of 350 ºC. SiO_2 thin films with thicknesses of 100 nm and 150 nm were prepared on p-type silicon (100) wafers, respectively. The extra 50 nm of the 150 nm films was etched away by a RIE system (FHR 150 × 4) using a gas mixture of CHF_3 and O_2, which provided a SiO_2 etch rate of 40 nm/min for a RF power of 400 W, a pressure of 4 Pa, a CHF_3 flow of 20 sccm, an O_2 flow of 3 sccm, a chamber temperature of 40 ºC, and a substrate temperature of 5 ºC. NiCr (Ni : Cr = 80 : 20) films were prepared on the untreated and RIE treated SiO_2 substrates by reactive sputtering of a high purity NiCr target in an Ar atmosphere. NiCr films with different thicknesses (8 nm, 16 nm, and 24 nm) were deposited by controlling sputtering time. The thicknesses of the obtained NiCr films were measured by a XP-200 step profiler and verified by sheet resistance tests.

Transmissions of the films were measured by a Fourier transform infrared spectroscopy (FTIR) system (Perkin Elmer Spectrum 400) while reflection measurements were taken by a THz time-domain spectroscopy (THz-TDS) system (EKSPLA) with an incident angle of 30 degree.

3. RESULTS AND DISCUSSION

The measured transmission curves of NiCr films with thicknesses of 8 nm, 16 nm and 24 nm deposited on untreated and RIE treated SiO_2 films are shown in Fig. 1. It suggests that the transmission of NiCr film deposited on a RIE treated SiO_2 film for each thickness is lower compared to that of NiCr film deposited on an untreated SiO_2 film. For spectral range of (1 ~ 12) THz, the decrease of transmission in (1 ~ 4) THz is more significant compared to the decrease in higher frequency.

The measured reflection curves of NiCr films with thicknesses of 8 nm, 16 nm and 24 nm deposited on untreated and RIE treated SiO_2 films are shown in Fig. 2. It can be seen that the reflection is also weakened in general by

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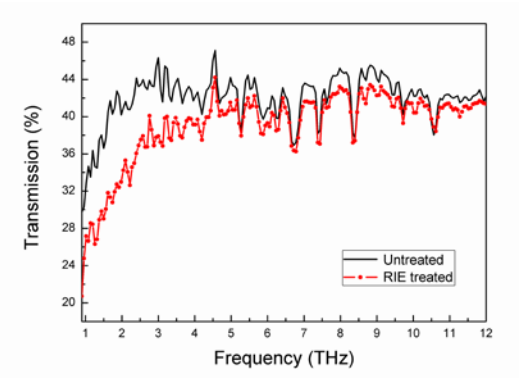
the RIE treatment and the most significant decrease occurs at (1.7 ~ 2.5) THz. The decreases of both transmission and reflection induced by the RIE treatment are more significant for NiCr film with a higher film thickness.

For NiCr film deposited on a dielectric substrate, absorption (A), transmission (T), and reflection (R) have the following relationship: $A + T + R = 1$. It can be concluded from the transmission and reflection curves that the absorption of NiCr film is enhanced for the transmission and reflection are both decreased due to the RIE treatment applied to the SiO_2 dielectric support film. This agrees with our earlier research reported in [11].



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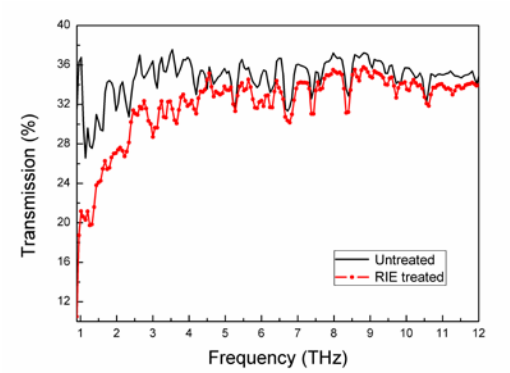

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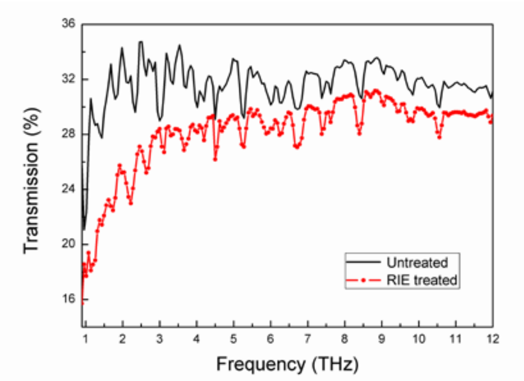

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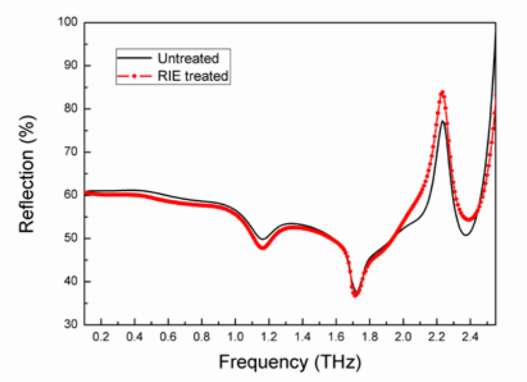
Fig. 1. The measured transmission curves of NiCr films in (1 ~ 12) THz with a thickness of 8 nm (a), 16 nm (b), and 24 nm (c) deposited on untreated SiO_2 films and RIE treated SiO_2 films

Fig. 3 shows the AFM images of NiCr films with thicknesses of 8 nm, 16 nm and 24 nm on untreated SiO_2 films and RIE treated SiO_2 films. It can be seen that for NiCr films with different thicknesses, roughened surfaces are induced by the RIE treatments. The effective surface area of NiCr film is increased due to nano – scale surface structures. The absorption of a metal film (A) consists of two components [12]: $A = A_{INTR} + A_{SS}$, where A_{INTR} is the intrinsic absorption of an ideally smooth surface and A_{SS} is the contribution due to nano-scale surface structures. It becomes clear that THz transmission and reflection of NiCr film are both decreased after RIE treatment mainly due to the enhanced absorption (A_{SS}).

In order to study the effect of RIE process on the dielectric substrate, AFM tests were done on RIE treated and untreated SiO_2 films, as shown in Fig. 4. It can be seen that a roughened surface of SiO_2 film with nano-scale surface structures is induced by the RIE treatment, which results in nanostructured NiCr film which is deposited on the RIE treated SiO_2 film later.



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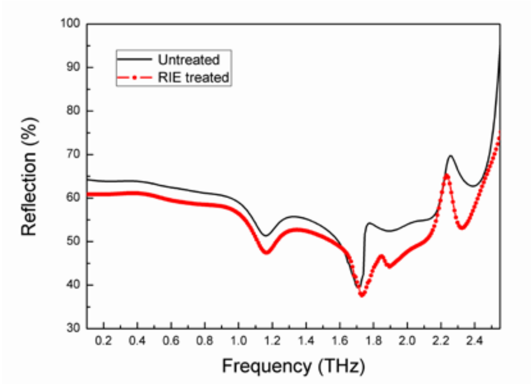

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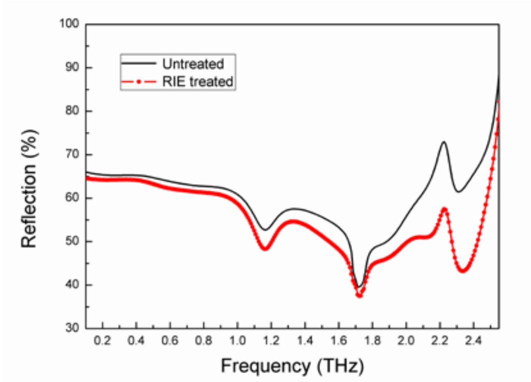

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Fig. 2. The measured reflection curves of NiCr films in (0.1 ~ 2.55) THz with a thickness of 8 nm (a), 16 nm (b), and 24 nm (c) deposited on untreated SiO_2 films and RIE treated SiO_2 films

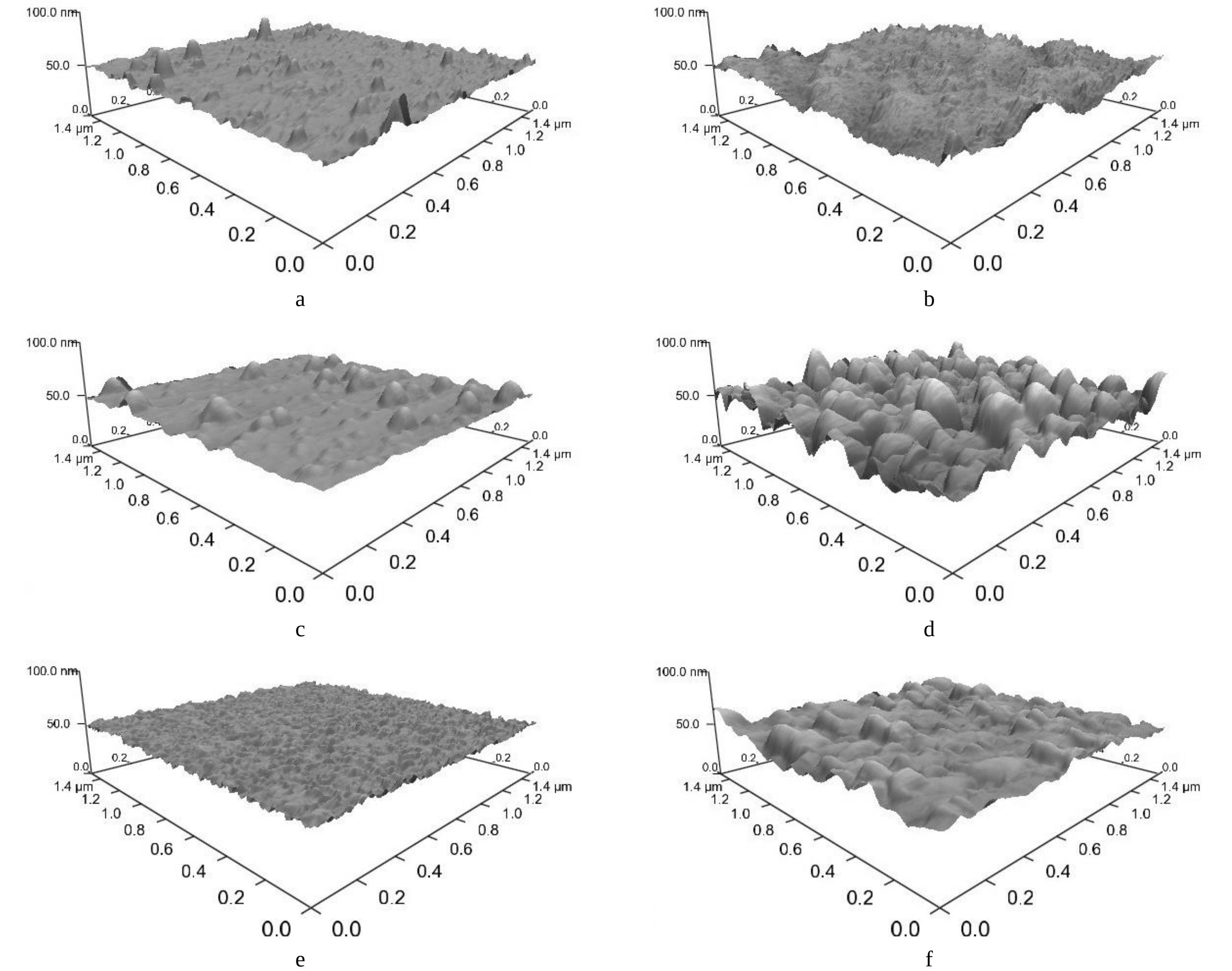

Fig. 3. AFM images of NiCr films with different thickness deposited on untreated and RIE treated SiO_2 films: a – 8 nm NiCr film on a untreated SiO_2 film; b – 8 nm NiCr film on a RIE treated SiO_2 film; c – 16 nm NiCr film on a untreated SiO_2 film; d – 16 nm NiCr film on a RIE treated SiO_2 film; e – 24 nm NiCr film on a untreated SiO_2 film; f – 24 nm NiCr film on a RIE treated SiO_2 film

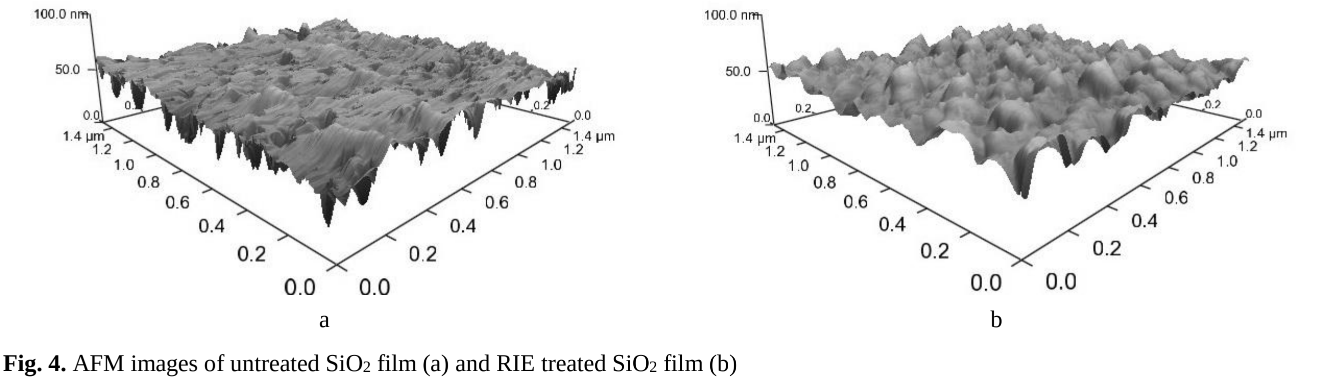

Fig. 4. AFM images of untreated SiO_2 film (a) and RIE treated SiO_2 film (b)

4. CONCLUSIONS

A MEMS-compatible process was suggested to improve THz absorption of metal film by applying a reactive ion etching (RIE) process to the dielectric support layer. To study the influence of RIE on THz transmission and reflection characteristics of metal film, RIE treatments were applied to SiO_2 dielectric substrates of nano – scale NiCr thin films with different thicknesses. Experimental results suggested that both transmission and reflection of NiCr film deposited on a RIE treated SiO_2 film were weakened compared to that of NiCr film deposited on an untreated SiO_2 film due to enhanced absorption. SiO_2 film surface was roughened by the RIE treatment which resulted in nanostructured NiCr film with a larger effective absorption area. More significant decreases of transmission and reflection were achieved for NiCr film with higher thickness. The most significant decreases of transmission and reflection occurred at (1 ~ 4) THz and (1.7 ~ 2.5) THz band in the measurements, respectively.

Acknowledgments

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