Vertical MIM metamaterial absorber for gas molecular sensing

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Metasurfaces have received significant attention for their ability to manipulate light. Recently we applied metasurface light absorber for improving the sensitivity of IR spectroscopy. Owing to its plasmonic interaction with incident light wave, and molecules, unwanted background and noises in IR spectroscopy were suppressed and molecular signals are enhanced. This technique has already been applied for self-assembled monolayer of 16-mercaptohexadecanoic acid molecules on the device surface and atto-molar (10^{-18} mol) level molecular sensitivity was achieved [1]. For liquid samples, we proposed a metamaterial absorptive device that incorporates nanofluidics to introduce target molecules into the hot spot region of the metamaterial [2, 3]. The device consists of metal square-disk array and metal mirror separated by a nanofluidic channel. When molecules with absorption that overlaps with the resonant mode of the metamaterial are introduced into the nanofluidic channel, a strong interaction between molecules and metamterial is excited, creating the reflection light within the absorption band of the metamaterial. Using this mechanism, we achieved a sensitivity of $\sim 10^{-4}$ molecules/$Å^2$, which is 2 orders of magnitude better than reported plasmonic induced IR detection methods.

In this paper, we propose a metasurface absorber with three-dimensional vertical-oriented metal-insulator-metal (v-MIM) structure for ultra-sensitive infrared spectroscopic gas sensing techniques [4]. The small footprint of the v-MIM structure allows for an increased integration density of the MIM structure, enabling the detection of gas molecules with suppressed background light and high selectivity in the mid-infrared region. We designed and fabricated the v-MIM structure with a nano-gap of 25 nm channel, which enabled the delivery of small molecules into hot-spot region. Figure 1 shows the scanning electron micrographs of the fabricated v-MIM array structure.

This v-MIM metamaterial absorber was applied to carbon dioxide and butane detection designing to exhibit a resonance at 4033 cm^{-1} and 2945cm^{-1} which spectral overlap with the C=O and $-CH_2$ vibration mode, respectively. The mutual coupling of these two resonant modes creates a Fano resonance, and their distinct peaks are clearly observed in the corresponding transmission dips.

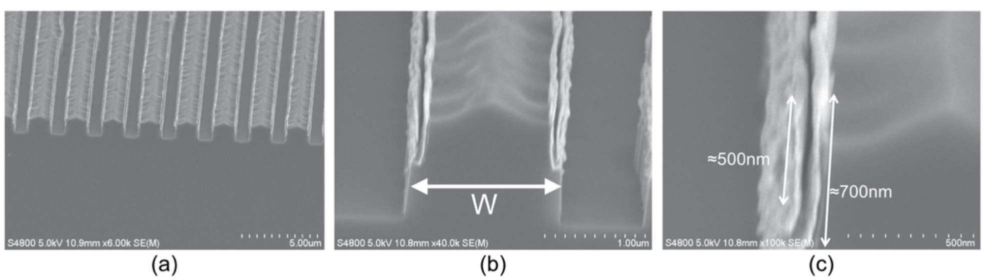

Figure 1. Scanning electron micrograph of the fabricated v-MIM structures.

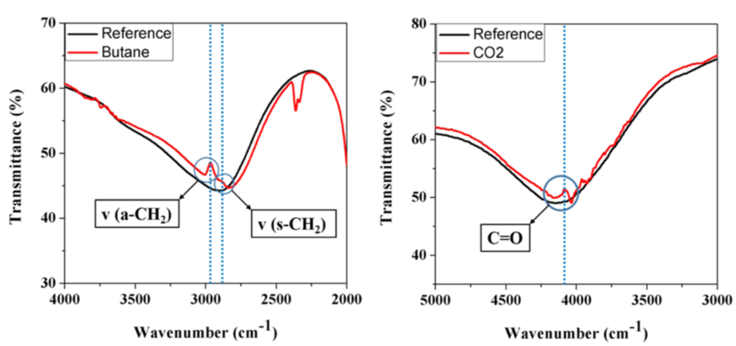

Figure 2. Experimental results of the butane and carbon dioxide detection.

References

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