Surface Plasma Wave Enhanced Infrared Detection

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Abstract

Surface plasma waves (SPW) offer an attractive enhancement for quantum-dot infrared photodetectors (QDIPs). We demonstrate strong enhancement in the detectivity (30×) for both top-surface metal photonic crystal (holes in a Au film) and back surface corrugated metal films. The corrugated metal film is particularly attractive for incorporation in a standard focal plane array processing sequence. The first fully operation SPW focal plane array camera is demonstrated. The long term vision is to encode both spectral and polarization information in a FPA readout greatly increasing the information content of infrared cameras.

1. Introduction

Recently, several research groups have demonstrated that the photoresponse of quantum dot and quantum well infrared photodetectors (QDIPs and QWIPs) can be enhanced by integrating a metal photonic crystal [MPC – a metal film perforated with a 2-dimensional (2D) array of holes] atop the devices[1-5]. The basic idea is to couple incident light to surface plasma waves (SPWs) propagating along and bound to the metal/semiconductor interface of an MPC, leading to enhanced responsivity and detectivity [1]. Both top side (holes in a metal film) and bottom side (corrugated metal film) have been demonstrated to give strong responsivity enhancements (up to ~ 30×).

2. Results

We have recently shown that for an MPC-integrated QDIP, substrate-side illumination (SSI) is more effective than air-side illumination [6] employed in previous SPW studies [1-4]. The MPC structure [Fig. 1(a)] can be optimized for direct coupling to the metal-semiconductor SPW without the need to accommodate transmission through the structure. Since light is incident from the substrate side in conventional focal plane arrays (FPAs), MPC for SSI in Fig. 1(a) is directly applicable to current devices. However, as illustrated in Fig. 1(a), the MPC requires air holes through the metal film, which would be filled by indium during flip-chip bonding to the read-out integrated circuit (ROIC). This would negatively impact the SPW coupling by adding a strongly absorptive element in direct contact with the SPWs. We have reported the use of a corrugated metal surface (CMS) in place of the MPC to resolve this problematic issue. As seen in Fig. 1(b), a CMS can be fabricated atop individual pixels of an FPA with the deposition of a thick metal film *before* flip-chip bonding. In SSI, the periodic corrugation at the metal/semiconductor interface provides the transverse momentum needed for the coupling to SPWs. Moreover, as shown in Fig. 1(b), such CMS can be embedded between a pixel and an In-bump without affecting the SPW coupling or any further FPA processing. The SPW excitation in this case is fully compatible with established FPA architectures and fabrication processes. In this work, both CMS and MPC devices are fabricated and compared with a reference QDIP to demonstrate the potential for improved infrared FPAs.

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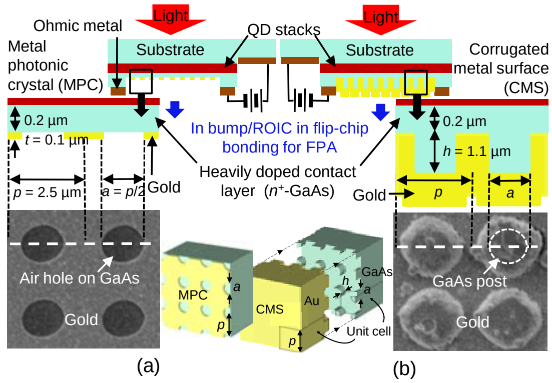

Fig. 1. Schematic cross sections (top and middle) and top-view SEM images (bottom) of (a) an MPC detector of t = 0.1 μm and (b) a CMS detector of h = 1.1 μm. The negative bias polarity is indicated. The illustration at the middle of each figure is an enlargement of the box in the top corresponding to the cross section along the dashed line in the SEM image.

Fig. 2 shows the 77 K responsivity curves for the structures shown in Fig. 1. The enhancement due to the SPW coupling is clearly evident.

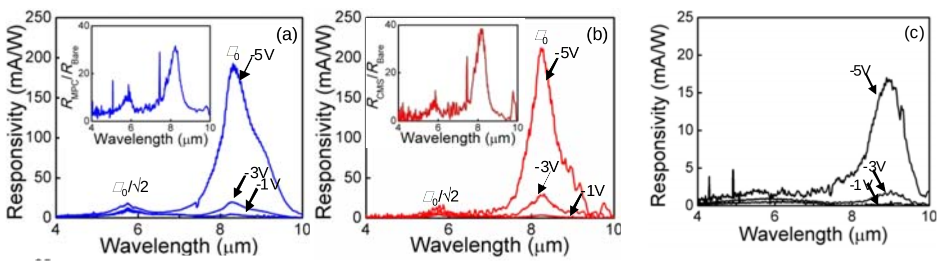

Fig. 2. Responsivity curves of (a) the MPC, (b) the CMS and (c) the bare detector with a bias variation from -1 to -5 V. The insets to (a) and (b) are the responses normalized to the bare detector showing ~ 30 to 40× enhancement at the fundamental SPW wavelength.

The integration of an MPC onto a focal plane array is shown in Fig. 3.

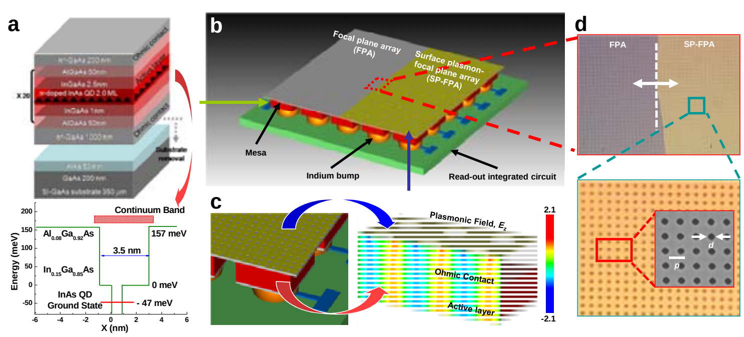

Fig. 3. Integration of a metallic photonic crystal (MPC) on a QDIP focal plane array. (a) epitaxial structure and band diagram; (b) MPC covering ½ of FPA; (c) detail of structure and simulation of SPW fields; (d) detail of MPC fabricated by interferometric lithography, p = 1.8 μm; d = 0.5 p.

Finally, Fig. 4 shows an image taken at 77K with this camera.

3. Conclusions

We have demonstrated a significant responsivity enhancement for surface plasma wave coupling to QDIP infrared detectors and focal plane arrays. Future work will optimize this enhancement and add spectral and polarization diversity for a significant enhancement in infrared camera performance.

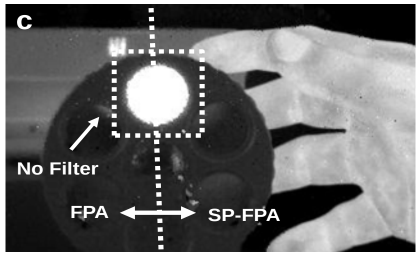

Fig. 4. Resonant enhancement in plasmonic DWELL camera. Representative image of the blackbody seen through the open slot (no filter) in the filter wheel assembly. Note the clear image of the human hand clearly showing temperature differences of less than 50 mK. Details of the spectral response will be presented.

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