INTRODUCTION

The second generation of infrared detectors based on HgCdTe is today a mature technology used in production in several companies in the world. In France, Sofradir, which industrializes HgCdTe IRCMOS infrared detectors, uses a technology transferred by CEA/LETI/Infrared Laboratory several years ago.

This technology is based on the very simple approach of planar n-on-p ion-implanted photodiodes. HgCdTe is grown by liquid-phase epitaxy (LPE) on the Te-rich corner by the slider technique. Detector array interconnection to silicon readout integrated circuit (ROIC) is made by hot welding with indium bumps.

From that time, this technology was continuously improved by LETI and Sofradir teams. Research conducted at LETI in collaboration with Sofradir in the last few years has led to new achievements. This includes improvements of the standard technology and development of new advanced technologies.

For the standard technology, progress in the field of crystal growth was obtained increasing the size and the quality of CdZnTe (4-in. ingots) and HgCdTe LPE (20 cm²) crystals. In the field of detector technology, reduction of the detector pitch (20 μm) allowed array size increase (up to 640 × 512). Most of these improvements are already available at Sofradir.

New advanced technologies undertaken at the Infrared Laboratory have led to feasibility demonstrations of advanced focal plane arrays. Some of them are presented in this paper.
Recent Developments of High-Complexity HgCdTe Focal Plane Arrays at Leti Infrared Laboratory

Several laboratories have already presented interesting results on focal plane arrays (FPAs) detecting either in the medium-wavelength infrared (MWIR)/MWIR$^1,2$ or in the MWIR/low-wavelength infrared (LWIR)$^3,4$ spectral bands. The size of the state-of-the-art arrays ranges between $64 \times 64$ and $256 \times 256$ pixels, with pitch between 60 and 40 $\mu$m, the smaller pitch only allowing spatial but no temporal coherence.

This article presents recent results on the fabrication and the characterization of dual-band HgCdTe MWIR/MWIR FPAs developed in the LETI Infrared Laboratory (LETI/LIR). These devices are $128 \times 128$ staring arrays with a 50-$\mu$m pixel pitch, allowing spatial coherence. The LETI/LIR has been working for several years to develop all the technological steps involved in the fabrication of dual-band FPAs: material growth, detector technology, and readout circuit design. Recent articles$^5,6$ focused on the molecular beam epitaxy (MBE) technology, have shown the good results obtained in the growth of MWIR/MWIR heterostructures.

**HGCdTe MBE Material: Growth and Characterization**

The MBE growth technique is well adapted to the multispectral infrared detection because it allows the growth of complex structures with several thicknesses, compositions, and doping levels. Advances in the MBE growth technique developed at the LETI/LIR laboratory have been described earlier.$^5$ CdZnTe (211) oriented substrates are used for the multispectral growth. They will probably be replaced in the future by heteroepitaxy on germanium$^6$ because of its better capability to produce in terms of larger substrate size, reproducibility, and manufacturing cost reduction.

Recent optimization has been done on growth parameters such as substrate temperature and the Hg, Cd, Te flux in order to improve crystalline quality, composition homogeneity, and surface morphology. Good surface morphology has been obtained with defect density measured in the $1 \times 10^2$ to $5 \times 10^2$ cm$^{-2}$ range. These defects, essentially due to voids or tellurium precipitates, are known to degrade the photovoltaic diodes.$^7$

The crystalline quality is investigated by using a high-resolution x-ray diffraction mapper. In the case of layers grown on CdZnTe substrates, we compare the full-width at half-maximum (FWHM) x-ray diffraction peak of the epitaxial layer to the substrate's one. About 200 measurements are performed in each experiment to obtain a precise map. The results show only a weak degradation, of about 20 arcsec, on our heterostructures compared to the FWHM of the initial substrate.

The etch-pit density (EPD) is measured on the HgCdTe surface with the Hähnert and Schenk$^8$ etching solution (HF, HNO$_3$, H$_2$O, CrO$_3$). The EPD initially measured at $5 \times 10^5$ to $9 \times 10^5$ cm$^{-2}$ has been decreased to $2 \times 10^5$ cm$^{-2}$, which is the average value routinely obtained on our single layer. This low EPD is one of the important conditions for the realization of MWIR/LWIR detectors.

Finally, we controlled by SIMS characterization the variation of the cadmium $x_{Cd}$ composition, and the accurate values of thickness and composition were calculated from IR transmission measurements.

**Detector Technology**

**Device Structure**

The cross section of a multispectral device is presented in Fig. 1, for a single bump per pixel structure. The SIMS profile of the multilayer structure and a scanning electron microscope (SEM) image of a detector array with a 50-$\mu$m pitch are shown on Figs. 2 and 3. Two bumps per pixel devices can also be fabricated, as mentioned in other papers.$^5,6$ The dual-band detector consists of two back-to-back n-on-p photodiodes, obtained by growing a four-layer heterostructure. The $x_{Cd} = 0.3$ layer allows detection of the 5-$\mu$m-wavelength radiation, while the $x_{Cd} = 0.4$ allows detection of the 3-$\mu$m-wavelength radiation. The barrier with $x_{Cd} = 0.7$ is necessary to reduce the cross-talk between the two photodiodes: the carriers created in one of the junctions cannot diffuse toward the other junction. This structure allows sequential detection of 3-$\mu$m- and 5-$\mu$m-wavelength radiation, depending on the bias applied to the diodes.

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**Fig. 1. Schematic cross section of two-color detector structure with one bump per pixel.**

**Fig. 2.** The $x_{Cd}$ profile of a MBE multispectral heterostructure made by SIMS with cesium primary ions.