Characterization of Loading in the Plasma Etching of HgCdTe and Related II-VI Materials for Infrared Focal Plane Array Fabrication

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Abstract

Infrared radiation detection has proven to be a technology with extensive applications, making impacts in fields as varied as industrial monitoring, firefighting, and astronomy. It is also heavily utilized throughout the modern military. The information obtained through infrared imaging is widely recognized to provide key strategic and tactical advantages to remote commanders and soldiers on the battlefield. These applications have motivated the focused pursuit of advancing infrared technology following WWII. In this field, HgCdTe has been a material of interest in infrared technology for over 40 years. First appearing in detector assemblies as a bulk-grown photoconductor in the late 1960s, HgCdTe is now used for state-of-the-art multicolor infrared focal plane arrays (IRFPAs) consisting of back-to-back photovoltaic heterojunctions grown by molecular beam epitaxy. Low dark-current and the fact that the cutoff wavelength can be varied as functions of both composition and temperature have made it the material of choice for infrared detectors. HgCdTe currently dominates the market for high-end military infrared sensing applications.

Although HgCdTe is a highly adaptable material, working with it has proven difficult. Controlling the ternary compound during growth is extremely challenging, and properly incorporating the dopants used further complicate matters. HgCdTe is a very soft, but brittle material, making handling a concern. Device fabrication on such a substrate faces many obstacles. Processes employed must be more delicate than is typically required for other semiconductors. The non-circular wafers limit the applicability of advances in general semiconductor processing. Also, its very small bandgap (less than 0.10eV for long-wavelength infrared detectors) makes HgCdTe particularly sensitive to damage and contamination. These technical factors, along with the limited market, have led to the material trailing other semiconductors in the adoption of advanced fabrication techniques. However, the demanding requirements of the next generation of large-format multicolor detector designs have forced the industry to progress. One area for which this is true is etching.

Whereas traditional HgCdTe IRFPAs are fabricated with a wet chemical etch, the reduced unit-cell size and deeper etch depth requirements of advanced designs have forced the industry to utilize plasma etch technology to achieve the necessary anisotropy. Electron Cyclotron Resonance etching systems have been the standard approach adopted during technology development. In order to minimize damage in the material, special etch chemistries were developed for HgCdTe (and the closely related material CdTe) that are substantially different from those employed in Si and III-V semiconductor processing. The etchant typically consists of an Ar and H_2 mixture, used in ratios with appropriate biases to produce predominantly physical etches. More recently, the push towards larger substrates and higher product volumes has led to investment in Inductively Coupled Plasma technology. This scale-up in size and rate has been accompanied by a complementary desire to improve process uniformity, repeatability and reliability in order to increase yield. The transition of the HgCdTe plasma etch process into a production-oriented role has led to complications similar to those experienced in other semiconductor industries. Of particular concern at the present time are plasma-etch loading phenomena, which lead to varying etch rates across samples and between runs.

Breaking the larger classification into two subsidiary categories, microloading and macroloading deal with the etch rate fluctuations on the local and global scale, respectively. Commonly referred to as etch lag because of the reduced etch rate observed in tight geometries, microloading leads to insufficient etch depths and incomplete isolation of IRFPA diodes. If focal plane elements are not properly reticulated, imaging capabilities are greatly deteriorated and in some cases ruined. Macroloading typically takes the form of etch rate variability as a function of the sample area. Classical loading results in decreasing etch rates with increasing sample sizes. Complex interactions between etchants and the sample material can lead to second order effects with significant and less predictable impacts as well.

We are currently engaged in an effort to develop an understanding of the loading mechanisms associated with HgCdTe and CdTe etch chemistry, to ascertain their potential impact, and to determine to what extent their effects can be limited. Significant work has been performed in order to characterize both microloading and macroloading. We have identified the conditions necessary for the onset of etch lag in HgCdTe. Figure 1 shows the empirically determined trendline that details the geometric conditions for etch lag onset. In the paper we will present this information in detail along with the measured trends that describe the sidewall profile evolution during plasma etching. Factors such as photoresist etch rate and ion angular distribution have been shown to contribute to the final profile. We will discuss the role of each of these in the plasma etch process and microloading. Also to be presented are our findings on macroloading issues. We have determined for specific etch chemistries that rather than the HgCdTe and CdTe etch rates being the primary source of variability, the majority of the deviation is observable in the photoresist etch rate. As shown in Fig. 2, these changes have been determined not to be dependent on the amount of photoresist present, but instead on the amount of exposed CdTe. We will present the data that led to these conclusions, and also explore variations in the etch chemistry in an effort to identify the specific reactions occurring. Finally, we will report on efforts to mitigate the macroloading impact and describe the implications in the fabrication of HgCdTe IRFPAs.

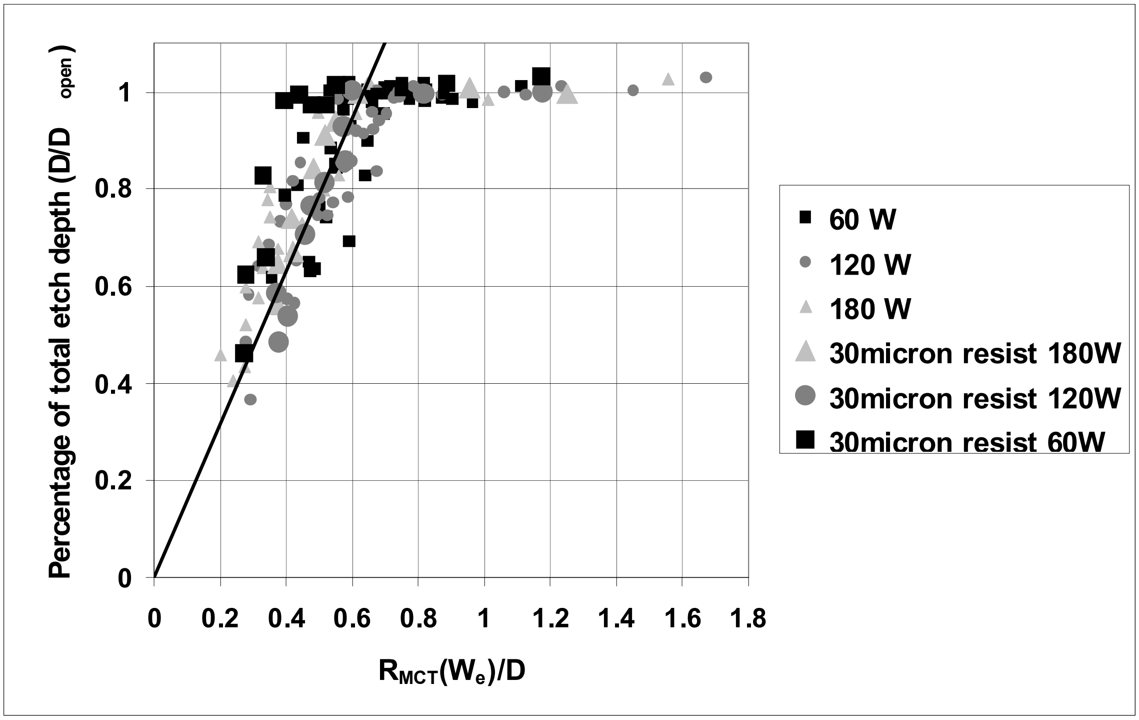

Figure 1. Trendline detailing the conditions necessary for the onset of etch lag for a variety of etching conditions. D/D_{open} is the ratio of the open area etch depth to the trench etch depth. $R_{MCT}(W_e)/D$ is the ratio of the etch rate and trench width product to the open area etch depth.

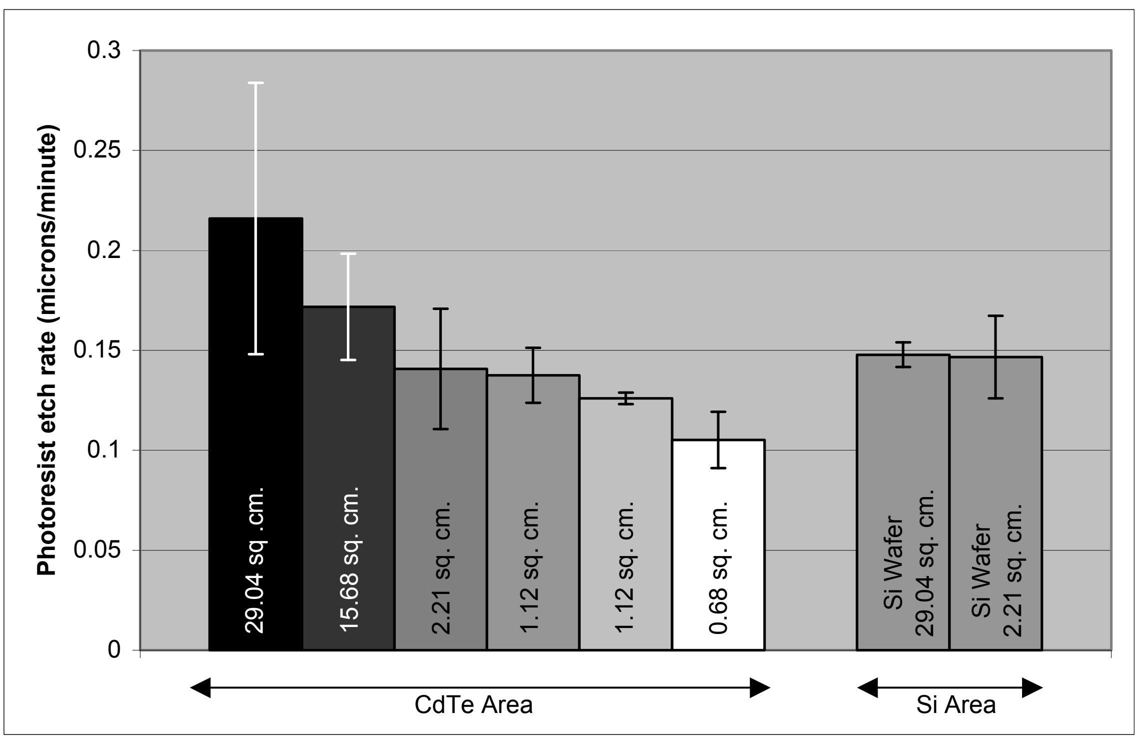

Figure 2. Photoresist etch rate as a function of semiconductor area. The photoresist etch rate increases with exposed CdTe area.