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CCD Image Sensors in Deep-Ultraviolet

Degradation Behavior and Damage Mechanisms

With 84 Figures

Springer

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Preface

As the deep-ultraviolet (DUV) laser technology continues to mature, an increasing number of industrial and manufacturing applications are emerging. For example, the new generation of semiconductor inspection systems are being pushed to image at increasingly shorter DUV wavelengths to facilitate inspection of deep sub-micron features in integrated circuits. DUV-sensitive charge-coupled device (CCD) cameras are in demand for these applications. Although CCD cameras that are responsive at DUV wavelengths are now available, their long-term stability is still a major concern. Since the energy of DUV photons is comparable to the band-gap energy of the silicon dioxide (SiO_2), photoreactions can occur in the SiO_2 layer of the CCD image sensor and introduce anomalous behavior.

Given the relative infancy of research in CCD-DUV interactions, publications in this area are somewhat sporadic. This book describes the degradation mechanisms and long-term performance of CCDs. The material presented in this book evolves from a comprehensive literature survey of the scientific research that underpins degradation behavior of CCDs.

Part I begins with an overview of CCD image sensors, and addresses the issues concerning CCD imaging in DUV, along with the common UV enhancement techniques adopted by the industry. Currently, backside-thinned back-illuminated CCD cameras are the leading contender from the standpoint of UV sensitivity. However, such cameras are expensive, and are vulnerable to radiation-induced instability, similar to other CCD designs. To understand the origins of CCD instability in DUV, knowledge of the reliability issues of the silicon-silicon dioxide ($Si\text{-}SiO_2$) system is essential. In Part II, the properties of Si, SiO_2, and $Si\text{-}SiO_2$ interface are described. On irradiation, the Si substrate, the SiO_2 layer, and the $Si\text{-}SiO_2$ interface interact with the incoming photons resulting in damage introduced to the CCD sensor. A discussion of the general effects of radiation is presented in Part III, where we consider the different types of defects and reactions that can arise in the $Si\text{-}SiO_2$ structures. Material interactions with UV radiation are examined in Part IV to identify the sources of instability in CCDs. Part V introduces experimental data that characterize thinned front-illuminated linear CCD sensors, when subjected to F_2 ($\lambda = 157\,\text{nm}$) excimer laser irradiation. Mechanisms responsible for the DUV-induced degradation behavior in CCD sensors are identified. Because the mechanisms are associated with the Si-SiO_2 system, the analysis can also be extended to other silicon-based UV sensor architectures. Potential design optimization techniques to improve the quantum efficiency (QE) and stability of CCD sensors at DUV wavelengths are discussed in Part VI, followed by concluding remarks and recommendations for future research. A better understanding of the mechanisms underlying DUV-induced degradation of CCD sensors can assist in the design and development of new-and-improved DUV-sensitive CCD sensors.

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