A Thesis for the Degree of Ph.D. in Engineering

Development of Silicon-polymer Hybrid Lenses for Infrared Optical Systems

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Thesis Abstract

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Thesis Title

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Thesis Summary

The demand for low-cost infrared (IR) optics has increased over the past decade. Ge has been primarily used for the IR lenses because of its excellent IR transmittance and refractive index; however, Ge is bulky, heavy, and expensive. As an alternative, Si is another IR material which is lighter and cheaper than Ge. However, as Si is a typical hard and brittle material, the ultraprecision machining of Si into complicated shapes, such as Fresnel lenses, is considerably difficult. When diamond turning is used for machining Si, the process is very time-consuming, and serious tool wear takes place. In recent years, IR polymers, such as high-density polyethylene (HDPE), have been developed which are much cheaper and easier to shape by thermal molding processes. However, the transmittance of HDPE is still very low, thus the thickness of HDPE lens must be extremely thin, which brings the problem that the lens stiffness becomes very low and thus the substrate is easily deflected. Accordingly, there is an urgent need for exploring alternative IR lens substrates. In this study, a novel IR optical lens substrate, namely, the Si-HDPE hybrid substrate, was proposed and developed. An extremely thin layer of HDPE was laminated to one side of a Si wafer by means of silane-crosslinking, and the mechanical strength is further improved by utilizing a mechanical lock structure. Thus, the resulting Si-HDPE hybrid lens substrate possesses the advantages of both materials, i.e., the high stiffness and IR transmittance of Si together with the high formability of HDPE. The hybrid substrate was fabricated by high-precision press molding where the pressure and temperature were strictly controlled. The surface integrity and form accuracy of the developed Si-HDPE hybrid substrates were experimentally investigated. The IR imaging evaluation showed that the hybrid substrate was useable for night vision and thermography.

Chapter 1 provided an introduction and an overview of the research background. The research significance and the research objectives were summarized.

Chapter 2 provided literature review of lens fabrication techniques, IR imaging systems, and the materials used for fabricating the IR lenses. Especially, methods that past researchers used for fabricating hybrid optical lenses were reviewed.

Chapter 3 detailed the steps of fabricating the Si-HDPE hybrid lens by press molding. The mechanism of combining HDPE to Si and the Si-HDPE interface phenomenon were investigated. The IR transmittance and other optical properties of the hybrid substrate were evaluated.

In Chapter 4, the fabrication process of a micro-structured HDPE layer on the hybrid substrate was presented. The effect of press molding parameters on lens surface integrity, form accuracy, and mold coating performance were examined. An in-situ observation system was established and numerical simulation of the forming process was detailed.

Chapter 5 described the IR imaging evaluation of the fabricated hybrid lenses. The lens performance was measured and tested using a home built IR imaging system. The captured night mode and thermography images demonstrated that the fabricated lenses were usable for IR imaging. The combination of different IR lens materials was also introduced to examine the compatibility of the Si-HDPE hybrid lens with other lens materials.

Chapter 6 consisted of the overall conclusions of the research and the future tasks.