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110°C range athermalization of wavefront coding infrared imaging systems

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Abstract:

110°C range athermalization is significant but difficult for designing infrared imaging systems. Our wavefront coding athermalized infrared imaging system adopts an optical phase mask with less manufacturing errors and a decoding method based on shrinkage function. The qualitative experiments prove that our wavefront coding athermalized infrared imaging system has three prominent merits: (1) working well over a temperature range of 110°C; (2) extending the focal depth up to 15.2 times; (3) achieving a decoded image being approximate to its correspondingin-focus infrared image, with a mean structural similarity index (MSSIM) value greater than 0.85.

Keywords: Computational imaging; Wavefront coding; Athermalization; Infrared imaging.

1. INTRODUCTION

An infrared imaging system finds a wide range of applications in the areas of military, space exploration and security surveillance. It outperforms a visible camera in term of night-vision ability, but tends to cause significant thermal defocus aberration. In order to keep good imaging quality over a wide range of environmental temperatures, athermalization should be considered at stages of designing, manufacturing and validating infrared imaging systems[1, 2].

Available approaches of infrared athermalization focus on the active mechanical[3], passive mechanical[4] and passive optical[5] measures. As one of typical computational imaging techniques, wavefront coding technique is a powerful hybrid optical-digital technique for increasing a focal depth of imaging and for widening an athermalization temperature range. By contrast, wavefront coding technique applied to the athermalization has many advantages such as avoiding less desirable and exotic infrared materials, relaxing manufacturing tolerances for some optical and mechanical elements, shortening time consumption of adjusting focus[6].

Poor wavefront coding imaging system has serious artefacts or noise amplification in final decoded image. The developed wavefront coding infrared imaging system by Ref.[7] reported the athermalization experiment. This experiment with athermalization range of 100℃ is only target observation in laboratory and its decoded images at high-low temperature are serious in artefacts. Our previous works report thermal effect[8], design and manufacture of optical phase masks[2, 9], a proposed decoding method based on shrinkage function[10], and a developed wavevfront coding athermalized infrared imaging[9]. This paper will further make a quantitative validation of our wavefront coding athermalized infrared imaging system in three aspects of athermalization temperature range, extension of focal depth, approximation to with in-focus image.

2.OUR WAVEFRONT CODING ATHERMALIZED IMAGING SYSTEM

For our wavefront coding athermalized imaging system, the Ge-material phase mask (as shown in Fig.1) is manufactured by nano-metric machining of ion implanted materials (NiIM)[11], which is based on the extrusion deformation theory. An ion implantation process is used to modify the surface mechanical properties of single crystal material before cutting[12]. Because Germanium lens with no coating has a low transmission, the cubic phase mask is antireflection coated for 8~14um wavelength.

Form measurements of our cubic phase mask are previously reported[9]. The measurement consists of form manufacturing error and surface roughness. The form manufacturing error is measured by a Taylor profiler of PGI1250 and its PV is approximately 770nm. For the measurement of surface roughness, our optical phase mask has two surfaces including a cubic surface and a plane one. Their surface roughness is measured by a white light interferometer of Wyko NT9300 respectively. The cubic surface has a roughness Ra of 5.44nm and the plane surface has a roughness Ra of 5.09nm. Evidently, the roughness measured value of the cubic surface approximates to that of the plane lens, which guarantees that the stray infrared emission caused by the surface roughness is rejected at low level. Both the measurement results of the form manufacturing error and the surface