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Design, Assembly, and Evaluation of Compact Telescope Based on CdTe Lenses for Spacecraft, Mobile Communications, and Harsh Environments

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Abstract
In this work, cadmium telluride (CdTe) lenses were used to design and construct a reasonably compact anti-shock telescope. The focal lengths of both lenses was 20 cm while the distance between these lenses was easily varied to determine the optimum design. The constructed telescope was evaluated throughout the relationship between magnification power and the distance between the objective and eyepiece lenses. A maximum magnification power of 20x was achieved at distance between the lenses of 21.6 cm. This telescope can be successfully used in spacecraft, mobile communication systems, and harsh environments.

Keywords: Telescope; Far-field imaging; Cadmium telluride; Magnification power
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1. Introduction

Imaging in space and harsh environments presents unique challenges due to extreme temperatures, radiation, and vacuum conditions. Space telescopes, such as Hubble and James Webb, use specialized cameras and infrared sensors to capture distant celestial objects. On planetary missions, rovers like Perseverance rely on high-resolution imaging to analyze terrain and search for signs of life. In deep-sea exploration, advanced sonar and optical imaging help map ocean floors and study marine life. Engineers design these imaging systems with durable materials and protective shielding to withstand extreme conditions, ensuring the successful capture of critical scientific data in otherwise inhospitable environments.

Compact telescopes for far-field imaging in space and harsh environments prioritize lightweight, durable, and thermally stable designs. They utilize advanced optical materials, such as silicon carbide or low-expansion glass, to withstand extreme temperatures and radiation. Their mirrors and lenses are precisely engineered to minimize aberrations while maximizing resolution. Deployable or folded optics, like those in space telescopes, allow for compact storage and efficient deployment. These systems integrate adaptive optics and active alignment mechanisms to counteract distortions from thermal expansion or mechanical stresses. Advanced coatings enhance light transmission and reduce reflections, optimizing performance for deep-space exploration and Earth observation.

Cadmium Telluride (CdTe) is a prominent II-VI semiconductor with a direct bandgap of approximately 1.44-1.5 eV, ideal for photovoltaic applications due to its high optical absorption coefficient. Physically, it is a crystalline compound with a zincblende structure, a high melting point (1041 °C), and is insoluble in water. Synthesis methods include vacuum evaporation, chemical bath deposition, solvothermal processes, and close-spaced sublimation, enabling formation of thin films, nanoparticles, or bulk crystals. CdTe's key applications are in thin-film solar cells, gamma-ray and X-ray detectors, and various optoelectronic devices like photodiodes and light-emitting diodes, offering a cost-effective and efficient alternative in renewable energy and sensing technologies.

In this work, cadmium telluride (CdTe) lenses were used to design and construct a reasonably compact anti-shock telescope. The focal lengths of both lenses was 20 cm while the distance between these lenses was easily varied to determine the optimum design. The constructed telescope was

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evaluated throughout the relationship between magnification power and the distance between the objective and eyepiece lenses. A maximum magnification power of 20x was achieved at distance between the lenses of 21.6 cm. This telescope can be successfully used in spacecraft, mobile communication systems, and harsh environments.

2. Experimental Part

Designing a telescope system with CdTe lenses and a 20 cm focal length involves careful selection of optical components, structural integrity, and application-specific requirements. Figure (1) shows the compact telescope designed, constructed, and evaluated in this work. CdTe is widely used in infrared (IR) optics due to its high transmittance in mid-to-far infrared wavelengths, making it ideal for space and communication applications. The magnification power (M) of a telescope is determined by the ratio of the focal length of the objective lens (f_o) to that of the eyepiece (f_e):

$$M = \frac{f_o}{f_e} \quad (1)$$

For instance, if an eyepiece with a 2 cm focal length is used, the magnification would be 10x.

For spacecraft and mobile communication applications, the telescope must be lightweight, resistant to extreme temperatures, and free from mechanical distortions. The assembly requires a rigid yet lightweight frame, often made from carbon composites or titanium, to ensure stability in microgravity. High-precision alignment of CdTe lenses is necessary for optimal focus and resolution. Adaptive optics may be integrated to correct distortions from atmospheric interference or mechanical vibrations. For mobile communication systems, the telescope can serve as a ground-based or space-based receiver, utilizing infrared wavelengths to enhance signal clarity and security in free-space optical communications.

Lens material is CdTe for infrared (IR) applications, optimized for mid-to-far IR wavelengths (3-25 μm). A 20cm focal length, high-quality anti-reflective coated CdTe lens was used as an objective lens. The eyepiece lens was designed based on required magnification; for a 10x magnification, an eyepiece with a 2 cm focal length is used. If higher efficiency and compactness are needed, a Cassegrain or Gregorian mirror system with CdTe optics could be employed.

Fig. (1) The compact CdTe-based telescope designed and assembled in this work

While CdTe is highly valuable for infrared optics and radiation detection, its direct use as a primary lensing material in conventional telescopes (especially for visible light) is severely limited by significant optical aberrations. The most dominant would be chromatic aberration, where different wavelengths of light refract at varying angles, leading to distinct focal points for each color and resulting in severe color fringing and blurred images. This is due to CdTe's relatively low Abbe number in the visible spectrum, indicating high dispersion. Additionally, monochromatic aberrations like spherical aberration, coma, and astigmatism would also be present, distorting image clarity, particularly for off-axis light sources, further hindering its suitability for high-fidelity imaging in the visible range.

Figure (2) illustrates the nonlinear relationship between incident light intensity and optical aberration in a CdTe lens. At low intensities (below 10^4 W/cm²), the aberration remains minimal and nearly constant, indicating operation within the linear optical regime where the refractive index is stable. However, as intensity increases beyond this threshold, aberrations grow rapidly due to nonlinear optical

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effects such as changes in the refractive index (Kerr effect) and thermal lensing. This behavior suggests a critical limit for optical applications involving high-power lasers, where exceeding certain intensity levels leads to significant wavefront distortion, compromising imaging performance and beam quality in precision optical systems.

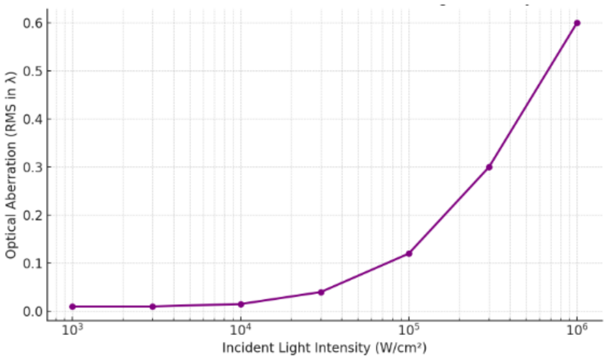

Fig. (2) This plot shows that optical aberration in a CdTe lens remains low and stable at low light intensities, but begins to increase rapidly once the intensity exceeds a nonlinear threshold (~10^4 W/cm²)

Carbon-fiber composites was selected as a frame material for lightweight, high-strength, and thermal stability. The encapsulation was done by sealed housing with thermal insulation to prevent CdTe degradation from extreme temperatures. Shock-absorbing mounts and active stabilization mechanisms were used to counteract mechanical vibrations in spacecraft or mobile systems.

The detector was assembled from CMOS sensors for high-resolution imaging. To correct distortions from atmospheric turbulence or spacecraft vibrations, adaptive optics were used. Cooling system was a passive radiators or cryogenic cooling for IR efficiency.

This assembly can be successfully used in spacecraft, optical communication, navigation, remote sensing, mobile Communications, free-space optical communication (FSO) for high-speed, secure data transmission, harsh environments, such as military reconnaissance, deep-space exploration, and lunar/Martian bases.

3. Results and Discussion

Figure (3) illustrates the relationship between the distance between the objective and eyepiece lenses and the magnification power of the telescope. As expected, the magnification power increases as the focal length of the eyepiece decreases. This is because magnification is given by Eq. (1) mentioned before. From the chart, we observe that when the eyepiece focal length is small (e.g., 1 cm), the telescope achieves high magnification (20x), meaning distant objects appear much larger. However, this also results in a smaller field of view and may introduce optical aberrations or image distortion. Conversely, as the eyepiece focal length increases (e.g., 10 cm), the magnification decreases (2x), leading to a wider field of view but less image enlargement.

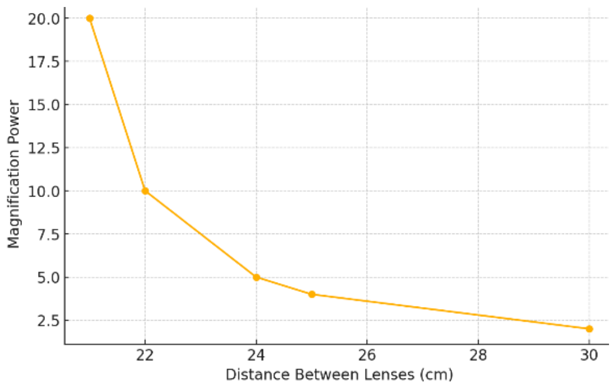

Fig. (3) Relationship between the distance between lenses and magnification power of the telescope

The distance between the objective and eyepiece lenses is approximately the sum of their focal lengths, affecting the overall telescope size. Telescopes used in spacecraft and mobile communication

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systems must balance magnification, size, and optical efficiency to ensure optimal performance while maintaining compactness.

For practical applications, a moderate eyepiece focal length (e.g., 2-5 cm) provides a good balance between magnification and usability. This ensures clear, stable images with sufficient resolution, making the telescope effective for space-based infrared imaging and optical communication systems.

4. Conclusion

In concluding remarks, 20cm-focal length CdTe lenses were efficiently used to design and construct a reasonably compact anti-shock telescope. The constructed telescope was evaluated throughout the relationship between magnification power and the distance between the objective and eyepiece lenses. A maximum magnification power of 20x was achieved at distance between the lenses of 21.6 cm. This telescope can be successfully used in spacecraft, mobile communication systems, and harsh environments.

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