Chemo-Mechanical Polishing of CaF_2 Crystal using Novel Slurry

LianLin Wang[1], Zhe Yang[1] and Jiang Guo[1,#]

1 State Key Laboratory of High-performance Precision Manufacturing, Dalian University of Technology, Dalian 116024, China
Corresponding Author / Email: guojiang@dlut.edu.cn

KEYWORDS: CaF2 Crystal, CMP, Novel Slurry, Surface Roughness

Due to its extremely high ultraviolet light transmittance, single crystal CaF_2 is the only optical material that can resist the damage of extreme ultraviolet short-wavelength light radiation, and has become an irreplaceable objective material in extreme ultraviolet photoetching system. With the development of semiconductor industry in recent years, the demand for high-precision single crystal CaF_2 is increasing. However, single crystal CaF_2 has soft and brittle characteristics, which is easy to produce surface defects and cracks during processing, and is a typical difficult material to process. Usually, CMP processing method is used to obtain atomically super-smooth surface on single crystal CaF_2 crystal. The composition of the polishing liquid of CMP is optimized, and the material removal rate is promoted by enhancing the chemical reaction between the surface of the CaF_2 crystal and the polishing liquid during the polishing process, so as to achieve the balance of chemical action and physical removal, so as to minimize the surface roughness. This study introduces a novel chemo-mechanical polishing slurry for achieving ultra-smooth surface quality of CaF_2 crystals. The slurry formulation leverages the synergistic effects of GO nanosheets and CeO_2 nanoparticles. The GO sheets effectively disperse the CeO_2 particles in deionized water, creating a uniform slurry critical for achieving a smooth and damage-free polished surface. CeO_2 nanoparticles, with a size of 20 nm, are well-suited for removing material and impurities from the CaF_2 surface during CMP. Their small size allows for effective polishing while minimizing surface damage. When the slurry comes in contact with the CaF_2 crystal during polishing at pH 10, the CeO_2 particles function through a combination of physical abrasion, potentially ceria-based reactions, and interaction with the GO sheets to remove surface irregularities and imperfections. GO sheets effectively conform to the surface during polishing, minimizing scratches and other defects. However, achieving an ultra-smooth surface at pH 10 is challenging, because in an alkaline environment, CaF_2 reacts to form new compounds, hindering optimal polishing. To address the limitations of using a pH 10 slurry with CaF_2, citric acid is introduced in the second phase. This adjusts the CMP slurry pH to 5 and leverages citric acid's ability to act as a chelating agent in this acidic environment. This prevents agglomeration of CeO_2 nanoparticles. As a result, a smoother CaF_2 surface is achieved. The results show that CaF_2 crystals prepared by two-phase CMP method have better surface quality. First, a polishing method consisting of an alkaline slurry at pH 10 (5 minutes) and an acidic slurry at pH 5 (20 minutes) was used, along with 20 nm CeO_2 at a concentration of 1 wt. %, and 0.02 wt. % graphene oxide nanosheets were added. Under these conditions, the surface roughness (Sa) reached 0.163 nm, the RMS reached 0.201 nm, and there were no obvious pits and scratches. The study successfully determined the optimal composition of the new slurry, resulting in an atomically super-smooth, non-damaging surface of CaF_2. This new discovery holds great promise for achieving ultra-smooth, non-damaging surfaces on soft and brittle materials.

.

Word count: Not more than 500 words