審 査 の 結 果 の 要 旨

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Wavelength-selective infrared light emission and detection using modified distributed-Bragg-reflector structures

Spectrally selective multilayer systems are promising technological components, owing to their efficiency, large range of available emission wavelengths, simplicity, and long lifetime. Particularly, spectrally selective thermal emission and sub-bandgap photodetection have attracted renewed interest in recent years. Spectrally selective thermal emitters tuned to emit thermal radiation in specific wavelength ranges have been used in applications ranging from electricity production (thermophotovoltaic) to cooling (radiative sky cooling) and anti-frost protection (car windows). Despite intensive effort, tailoring readily available thermal radiation into well-resolved and tunable emission at a single wavelength has yet to be achieved. Moreover, sub-bandgap photodetection at a single wavelength in the infrared region is also of technological importance. In this work, WANG proposes multilayer structures that realize spectrally selective emission and detection by introducing optical Tamm states in modified distributed-Bragg-reflector structures. Particularly, WANG reports a modified optical Tamm state structure realizing a spectrally selective thermal emitter with the smallest reported emission width in the infrared region. Moreover, WANG reports sub-bandgap photodetection using a Tamm-plasmon-structure coupled to a hot-electron photodetection structure consisting of a metal-semiconductor-ITO multilayer. The thesis manuscript consists of four Chapters.

In Chapter One, the excitation of optical states related to the interfaces of one-dimensional structures is first introduced with a particular emphasis on Tamm plasmons and optical Tamm states. A literature survey is presented focusing on structures realizing thermal emission with spectral selectivity and photodetection with sub-bandgap excitation, and clarifying the potential advantages of one-dimensional structures.

In Chapter Two, the proposed spectrally selective thermal emitter is designed by modifying a structure that supports an optical Tamm state and consists of two distributed Bragg reflectors on a metal layer. In this structure, the forbidden energy bands of the distributed Bragg reflectors suppress thermal radiation at wavelengths outside the resonance wavelength, resulting in an ideal thermal emitter with a single well-defined and strong emission peak that rapidly falls off to near-zero background emission away from the resonant wavelength. In contrast to recent designs with quality factors on the order of 10^2, the proposed modified optical Tamm state structure achieves a quality factor on the order of 10^3 (the measured reflectance dip has a quality factor of 961 and the thermal emission achieves 780).

Furthermore, by taking advantage of the temperature-sensitivity of the constituent materials and the strong field confinement, the emission wavelength of the thermal emitter is tuned by controlling the operating temperature. This ultra-narrowband and wavelength-tunable thermal emitter is ideal for low-cost miniaturized spectrometers in a wide range of applications.

In Chapter Three, the proposed spectrally selective photodetector takes advantage of a Tamm plasmon structure to realize photodetection at sub-bandgap energies of semiconductor materials with a planar structure that does not require lithography. If the Tamm plasmon structure, consisting of a dielectric distributed-Bragg-reflector (DBR) and a metal film, enables strong field localization at the metal/dielectric interface that efficiently excites photo-induced carriers, the collection of these photo-induced carriers remains difficult. For photodetection purposes, the metallic film is replaced by a metal-insulator-metal that can generate hot electrons with a good spectral selectivity when the TP mode is excited. Recently, an Au-ZnO-Au (M-I-M) structure positioned below an eight-pair Al_2O_3/TiO_2 DBR was proposed and numerically investigated as a hot-electron photodetector. This structure achieves a sharp and strong reflectance dip that indicate a good wavelength-selective property. However, the theoretically predicted net photocurrent remains small due to the use of the symmetric metal-insulator-metal structure that generates opposite flows of hot-electrons. To address this issue, WANG proposes and demonstrates a Tamm plasmon structure coupled with a hot-electron photodetector consisting of a metal-semiconductor-ITO structure sitting on the top of a seven-layer distributed Bragg reflector structure. The M-S-ITO structure is used instead of the conventional M-I-M structure to create a net flow of hot electrons from the top Au film to the ITO film. Low-barrier ohmic contacts are formed at the interfaces of the M-S-ITO junction so that a large photocarrier current can be collected. The proposed design can not only guarantee a large photoresponse within a stable structure but also realize a narrowband wavelength-selectivity property (bandwidth of 43 nm at a wavelength of 1581 nm). A photocurrent at the TP resonance wavelength of 8.26 nA/mW is achieved, and the photoresponse decreases by more than 80% when the illumination wavelength is varied by only 52 nm (from 1581 to 1529 nm). As the first experimental result for Tamm-plasmon-structure coupled to a hot-electron photodetector structure, this study paves a way towards realizing high-performance, lithography-free, and wavelength-selective hot-electron photodetectors with a planar structure. Owing to a sub-bandgap photodetection realized by the hot-electron photoemission, the widely-used wide-band-gap semiconductor ZnO (3.3 eV) could be employed to detect light with low photon energy (around 0.8 eV), which extends the usage of the wide-band-gap materials.

Chapter Four gives the general conclusion of the thesis.

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