Realizing Ultrafast Ferroelectric Switching with Terahertz Nanogap Metamaterials

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In ferroelectric materials, spontaneous polarization represents stable states of ordered electric dipoles within a double well energy landscape. This type of dipole can switch between two distinct energy minima when exposed to an external electric field, making it ideal for non-volatile memory applications [1]. In the past, polarization switching has been accomplished by electrical alternating currents, but due to the nanosecond switching rate of the alternating fields, the observations have been limited to the switched final state of polarization. As a result of the advent of time-resolved spectroscopy using laser pulses, non-equilibrium dynamics of ferroelectric materials can now be studied. Because of its low coercive fields, light-driven ferroelectric polarization dynamics have been investigated in perovskites. However, sub-picosecond switching in conventional ferroelectrics remains challenging due to the strong depolarization fields and domain interactions generated during switching. Recently, HfO_2 stands out as a promising candidate for sub-picosecond switching because the domain-domain interaction energy approaches zero [2]. These extraordinary properties might enable light-induced fast polarization dynamics because the extremely localized and individually switchable polar domains are driven by flat phonon bands [2]. Nevertheless, there are several challenges associated with this technology, including its large coercive field of above 1-2 MV/cm and its orthogonal relationship between the electric field of light and ferroelectric polarization in typical planar configurations.

In this work, we demonstrate an unprecedented ultrafast ferroelectric polarization switching in terahertz nanogap metamaterials combined with ferroelectric $Hf_{0.5}Zr_{0.5}O_2$ (HZO) films using a single-cycle terahertz (THz) pulse, where the enhanced THz electric field up to 8 MV/cm can colinearly switch HZO's polarizations. Monitoring sub-1 picosecond (ps) switching with a resolution of femtoseconds revealed an S-shaped hysteresis, which captured the negative capacitance. Additionally, we observed a clear wake-up effect in HZO nanogaps after irradiation with over 10^8 THz pulses.

References

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