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Polarization-Dependent Vanishing of THz Reflectance in Aligned Carbon Nanotube Films

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1. Introduction

Recent advances in fabricating macroscopic aligned films of carbon nanotubes (CNTs) have enabled new exciting fundamental studies and applications [1]. Particularly, these films show hyperbolic optical properties promising for a refractory nanophotonics platform [2] and can be used as excellent terahertz (THz) polarizers exhibiting virtually no attenuation (strong absorption) when the THz polarization is perpendicular (parallel) to the CNT axis [3]. Here, we report on polarization-dependent THz time-domain spectroscopy (TDS) measurements on a macroscopically aligned film of single-wall CNTs (SWCNTs) on a silicon substrate in transmission geometry.

2. Methods and Results

A film of thickness 45±3 nm was produced by the controlled vacuum filtration (CVF) method and then transferred onto an undoped silicon substrate. The CVF method yields a wafer-scale (diameter ~ 2 inches) crystalline SWCNT film in which nanotubes are nearly perfectly aligned (with nematic order parameter $S \sim 1$) and maximally packed (~1 nanotube per cross-sectional area of 1 nm^2) [4,5]. THz pulses were generated via optical rectification and probed in the time domain via electro-optic sampling. For polarization-dependent measurements, the sample was mounted onto a rotation stage. By analyzing THz waveforms in the time domain, we observed complete disappearance of the second pulse (which is usually present due to the finite thickness of the substrate) at a "magic" polarization angle of 30° as shown in Figure 1. The second pulse vanishes only when output polarizer is oriented as input THz polarization but is present for output polarizer oriented perpendicular to the input THz polarization.

Qualitatively, the observed effect can be understood in terms of polarization rotation. As a THz pulse propagates through the CNT film, its polarization rotates because the electric field components parallel and perpendicular to the alignment direction are attenuated differently and have different phase velocities. Similar polarization rotation occurs for the second (reflected) THz pulse when it is reflected from the film/substrate interface. Therefore, the polarization of the second THz pulse can become orthogonal to the detection polarizer. The 'magic" angle at which reflectance vanishes depends on the anisotropic complex refractive index of the CNT film. In addition, we investigated tunability of the magic angle with respect to substrate and film thickness.

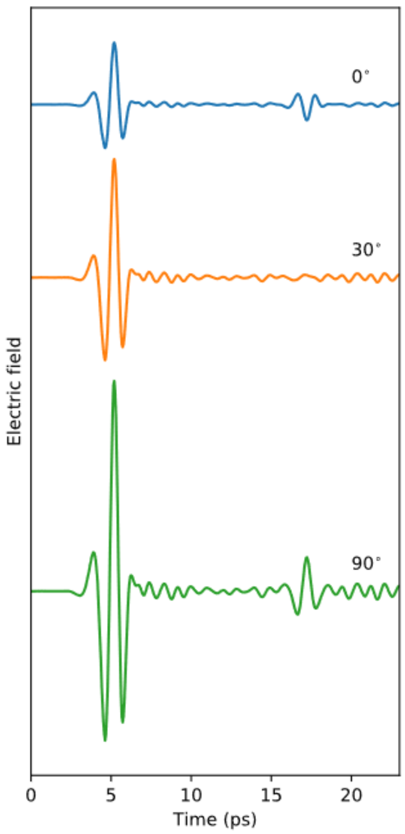

Figure 1. THz-TDS waveforms at different angles between CNT alignment direction and THz field polarization.

3. Conclusions

In summary, we have studied aligned CNT films by THz time domain spectroscopy. The second (reflected) pulse, which is reflected from the back of the substrate, vanishes when the input THz pulse polarization is at the magic angle (30° for Si substrate) with respect to the alignment direction of carbon nanotubes. The quality of CNT alignment is the key to observe this effect. This work is of great importance to developing novel THz devices based on highly aligned CNT films.

References

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