Large optical form-birefringence of nanowire ensembles

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We observe strong anisotropy in the optical response of dense ensembles of GaP nanowires epitaxially grown on a (111) GaP wafer. Dense, disordered nanowire layers were obtained using the VLS-growth mechanism starting from a gold-film catalyst. Optically transparent, thin nanowire films show large form birefringence perpendicular to the wire axis, $\Delta n = 0.15$ for a 20% nanowire density. We compare this value to the predictions from various effective medium models.

Introduction

Semiconductor nanowires are quasi-1D structures. This will lead to strong anisotropies in

- Light scattering
- Luminescence
- Optical birefringence

Optical form birefringence can be observed in optically thin layers of nanowires with high nanowire density.

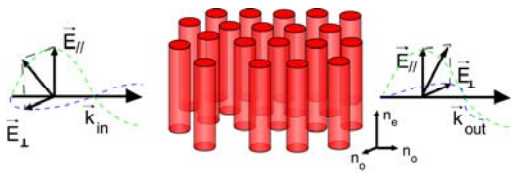


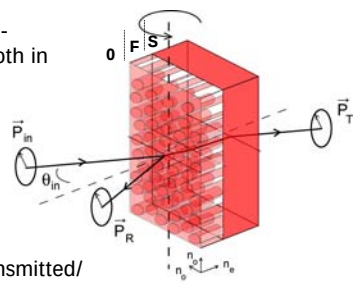
Figure 1 Form birefringence means different refractive indices for polarization directions perpendicular and parallel to the nanowire axis due to geometric anisotropy.

Experiments

Birefringence is detected by angle-dependent polarization rotation both in

- Reflection
- Transmission

at constant optical wavelength λ=632 nm



For 45° incident polarization we measure the projection of the transmitted/ reflected light parallel and cross-polarized to obtain the contrast ratio $I_{\perp}/I_{//}$.

Modelling of optical elements using transfer matrices can be used to fit a value for the birefringence of $\Delta n = 0.15$ for the 2 μm long wires and $\Delta n = 0.1$ for the 4 μm wire ensembles.

Reflected light **Transmitted light**

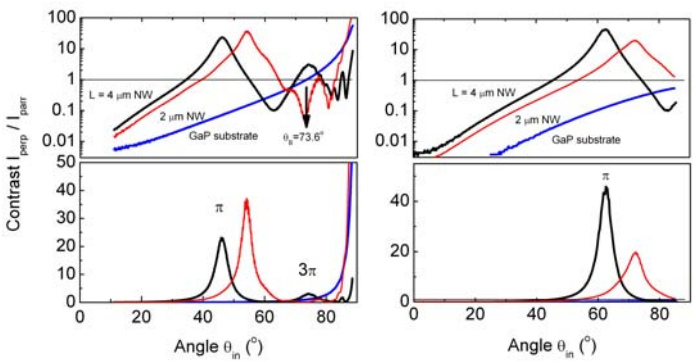


Figure 3 Measured polarization contrast I_{perp} / I_{parr} of transmitted (left) and reflected (right) light from (red) 2 μm GaP nanowires, (black) 4 μm GaP nanowires, and (blue) no nanowires, both shown on(a) logarithmic and (b) linear vertical scale.

Epitaxial nanowire growth

GaP nanowires grown on (111) GaP substrate at Philips research by the group of Erik Bakkers:

- Vapour-Liquid Solid growth mechanism
- Epitaxial growth leads to oriented wires
- Thin gold film provides large wire densities (20%)

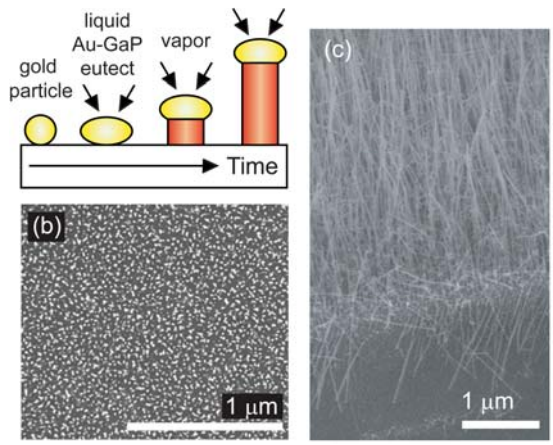


Figure 2 (a) VLS growth mechanism for GaP nanowires. (b) SEM top view of epitaxial GaP nanowires, with volume fraction of ~20% and wire diameters around 20 nm. (c) side view of the GaP nanowires.

Interpretation

Microscopic models for form birefringence:

- Extraordinary n_e is given by geometrical sum of mixing components (n_{air}, n_{GaP})
- Ordinary n_o requires effective medium theory (Maxwell Garnett, Bruggeman), or extended Boundary Condition model
- Large variation in values for Δn is obtained for various models
- BC model corresponds best to experimental result on nanowires

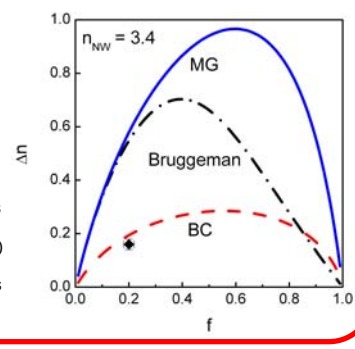


Figure 4 Effective medium models for birefringence. (Blue) Maxwell Garnett, (Black) Bruggemen, (Red) BC method, Data point indicates measured value for GaP nanowires

Conclusion

Large form birefringence of Δn=0.15 is observed for dense GaP nanowire ensembles. Volume fractions higher than 20% will be available in the near future using controlled shell growth.