AlGaAs nanowires for phase-matched SHG in the telecom range

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Phase-matched three-wave mixing is possible in optically isotropic zinc-blende materials, thanks to quasi-phase matching occurring when the interacting fields propagate along a curved path about a principal dielectric axis [1]. Following this scheme, efficient Second Harmonic Generation (SHG) was recently demonstrated in GaAs [2] and AlGaAs microdisks [3], and it was predicted in curved waveguides [4].

We designed and fabricated snake-shaped nanowires for SHG in the optical telecom range, both in fully suspended Al₀.₁₉Ga₀.₈₁As waveguides and in Al₀.₁₉Ga₀.₈₁As on aluminium oxide. These waveguides are composed by a series of quarters of a ring, as sketched in Fig. 1. The sign of $\chi^{(2)}$ is inverted every two adjacent 90° arcs. By doing so, it is possible to perform an “effective” quasi-phase matching, without any technological burden associated to $\chi^{(2)}$ domain inversion [1].

![Fig. 1. Parameters for the design of snake-shaped waveguides](image)

The coherence length, $L_c$, the maximum distance over which the nonlinear interaction is constructive, for SHG, depends on the difference between the effective indices at the second harmonic (SH) and the fundamental frequency (FF):

$$L_c = \frac{\lambda}{4n_{SH}(\lambda_{SH}, w, h) - n_{FF}(\lambda_{FF}, w, h)}$$

Since these effective indices depend on the geometry of the waveguide ($w, h$) and $R_c = L_c/\pi$, Eq. 1 relates all the parameters in the waveguide geometry. To minimize propagation losses, one needs $R_c \ll w$, and thus maximise $L_c$. The coherence length as a function of the wavelength and the width of the waveguide is shown in Fig. 2a for a suspended waveguide and in Fig. 2b for a waveguide on aluminium oxide.

Both samples have been fabricated on a (100) GaAs wafer. For the first one, a 123nm Al₀.₁₉Ga₀.₈₁As layer is grown over an Al₀.₈₀Ga₀.₂₀As sacrificial layer, while for the second one, we grow a 100nm Al₀.₁₉Ga₀.₈₁As layer on an Al₀.₉₈Ga₀.₀₂As layer to be oxidised after lithography and etching. A few electron-microscope images are shown in Fig. 3.

Both waveguides are excited by a continuous-wave laser at a FF wavelength of 1.55µm, and we collect both FF throughput and SH output at 775nm with lock-in detection. End-fire input and output light coupling is performed via micro-lensed fibres and inverted tapers. The latter, of the type shown in Fig. 3b, are optimized for FF TE-polarized light at the input and SH TM-polarized light at the output.
Fig. 2. Coherence length versus $\lambda_{FF}$ and $w$, for the suspended waveguide (a) and for the waveguide on an aluminium-oxide substrate (b).

Fig. 3. Scanning-electron-microscope pictures of a suspended waveguide: (a) bent geometry; (b) inverted taper for end-fire light coupling.

Ideal losses in snake waveguides are of two types: 1) radiation losses at the bent interface between the waveguide and the air; and 2) losses due to the non-ideal mode overlap at the waveguide sections where the sign of the snake curvature changes. Simulations performed with COMSOL on the suspended waveguides predict them to be smaller than 1dB/cm for $w = 0.75$ µm and $R_c = 20$ µm, as well as for $w = 1$ µm and $R_c = 50$ µm. In such waveguides, the calculated SHG conversion efficiencies are $\eta_{SHG} = 7x10^3$ W$^{-1}$cm$^2$ and $\eta_{SHG} = 4.5x10^3$ W$^{-1}$cm$^2$, respectively.

Although the overall losses also include scattering and residual absorption losses due to non-ideal fabrication and materials, their preliminary measurements show the good potential of high-index-contrast snake-shaped AlGaAs nanowires for three-wave mixing.

References:


