Planar waveguide coupler based on tilted Bragg gratings and a discrete cladding mode

Mathias J. Weisen, Matthew T. Posner, James C. Gates, Corin B. E. Gawith, Peter G.R. Smith, Peter Horak
Optoelectronics Research Centre, University of Southampton, Southampton, UK
m.j.weisen@soton.ac.uk

Abstract

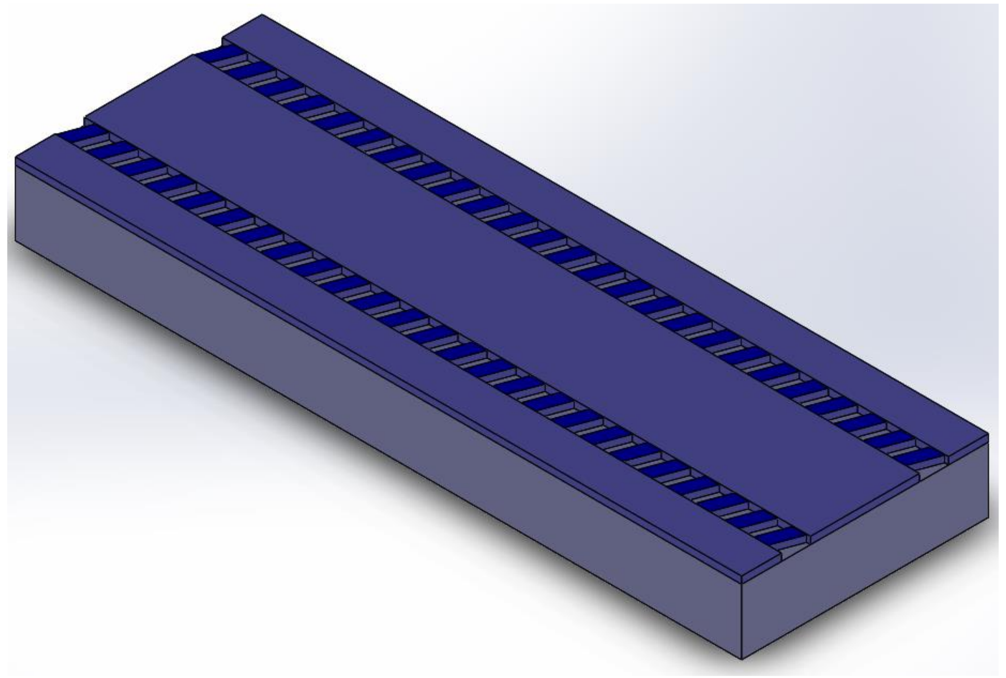
A new type of planar waveguide to waveguide coupler is presented based on two parallel single-mode waveguides written in the same ridge structure. Identical tilted gratings are used to couple light between the waveguide using the modes of the ridge. The bandwidth of the device can be controlled by varying the length. A transfer efficiency approaching 100 % is shown to be possible in this system.

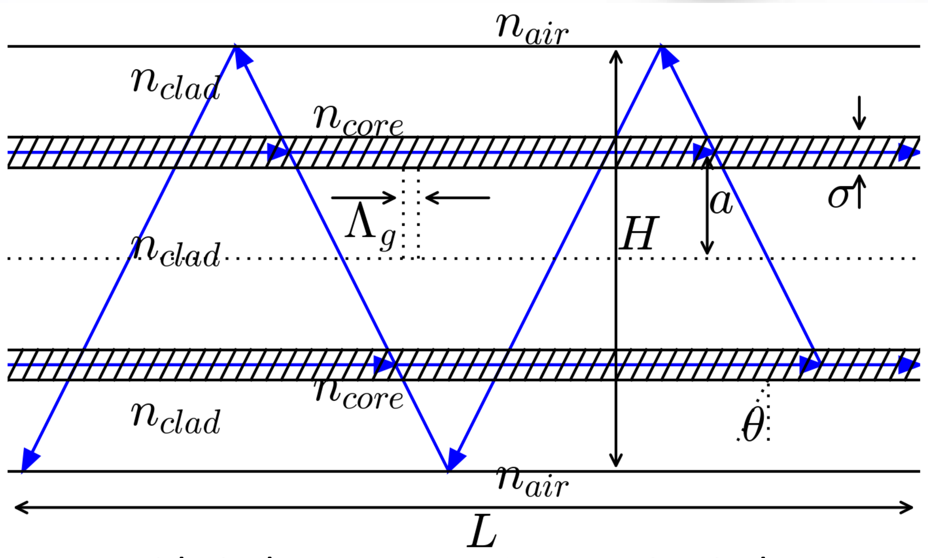
Introduction

- We have recently developed tilted Bragg grating technology for use in planar photonics [1].
- Can be used to couple light efficiently between waveguide and radiation/cladding modes.
- An integrated coupler based on two 45° tilted gratings has already been demonstrated [2], but with large losses due to **leakage into radiation modes**.

We simulate a new device that overcomes this limitation:

- Single ridge structure containing two parallel waveguides.
- Identical tilted gratings in each waveguide to couple to cladding modes.
- Parameters chosen to couple to a single backward propagating cladding mode.
- Power transfer between waveguides forms a coupler.
- **Bandwidth controlled by grating parameters.**

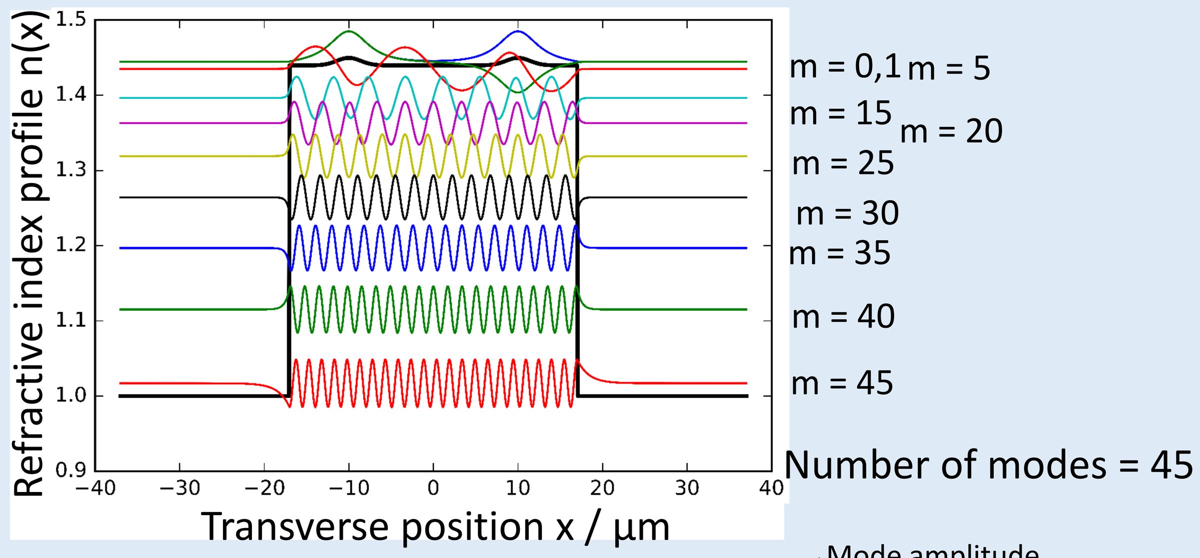




Δn: waveguide index contrast, Δn_g: grating index contrast
λ_0: Free space wavelength, λ_B: Bragg wavelength

Model

Transverse refractive index of structure and modes:



Coupled mode theory [3]:

$$\frac{dR_m(z)}{dz} = i\left[\frac{K_g}{2} - \beta_m\right] + \frac{1}{2}\sum_n R_n c_{mn} e^{-i\varphi_{mn}}$$

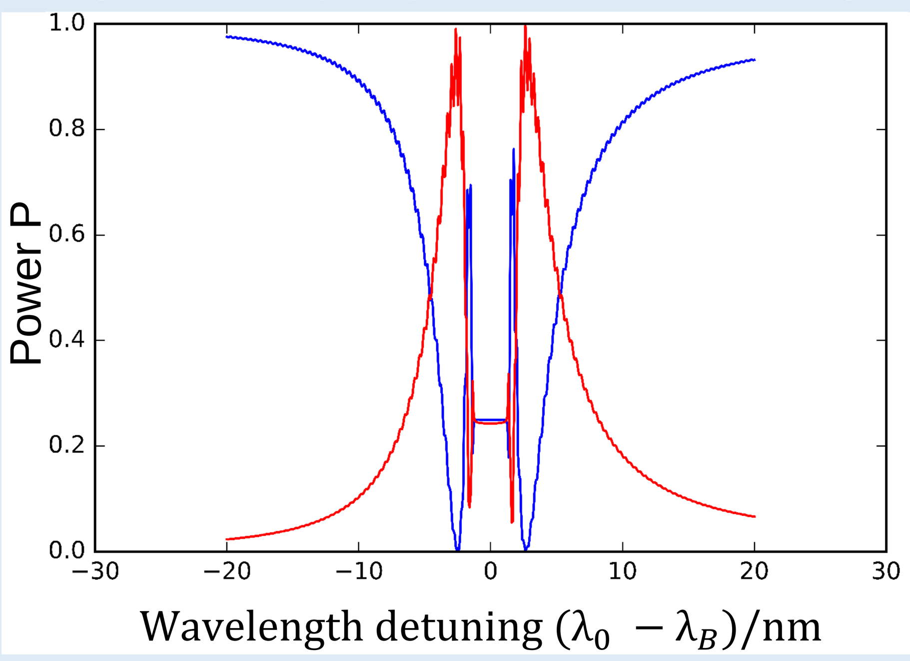
Mode amplitude; Coupling coefficient; Grating period; Mode propagation constant

- c_{mn} found using an overlap integral.
- Solved numerically as an eigenvalue problem.

Equation considers only coupling between counter-propagating modes.

Results

Waveguide output power vs wavelength



H = 34 µm, n_{clad} = 1.4398,
a = 10 µm, σ = 2.0 µm,
Δn = 0.01, Δn_g = 0.001,
λ_B = 1.55 µm, Λ_g = 586.6 nm,
θ = 17.19°, L = 20 mm

Couples to mode 35

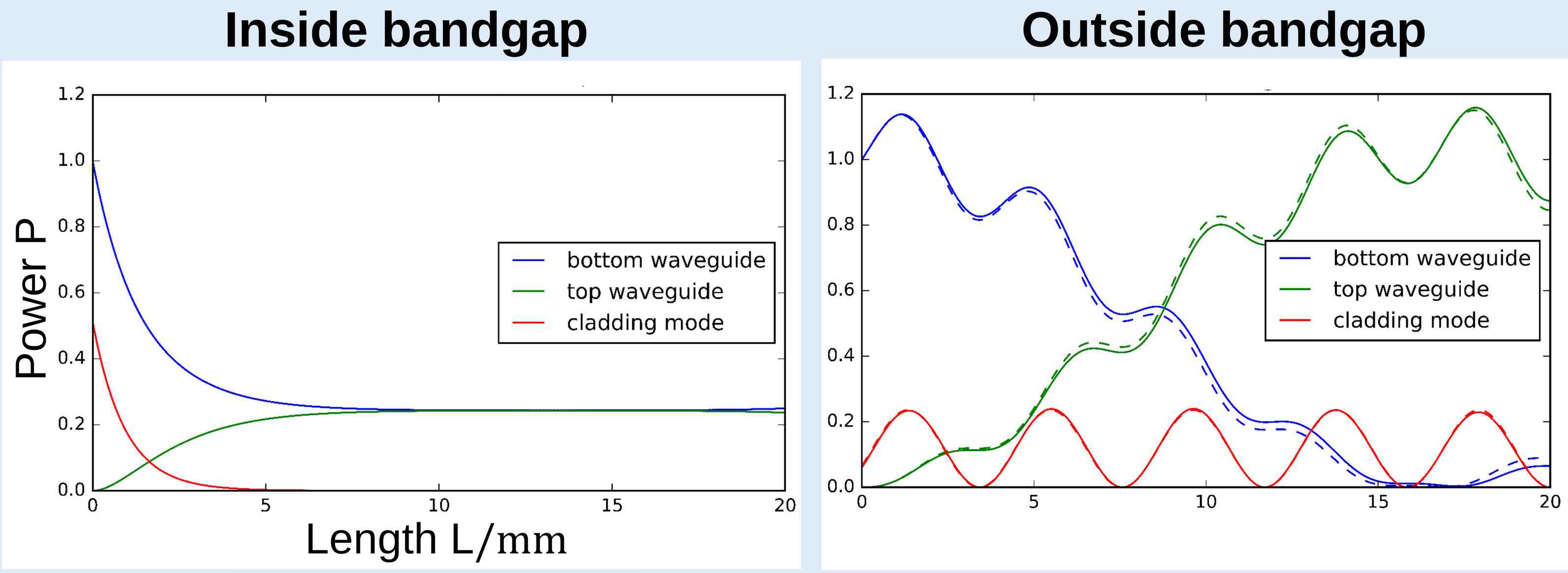
Power at bottom (blue) and top (red) waveguide outputs.

Wavevector phase mismatch $\Delta K = K_g + \beta_2 - \beta_0$

- With one cladding mode, eigenvalues are $\gamma_0 = \frac{i\Delta K}{2}, \gamma_\pm = \pm\sqrt{2c^2 - \Delta K^2}$
- Photonic bandgap found in region where $\Delta K < \sqrt{2}c$, $\gamma_\pm$ real:
  - One quarter of the light in each waveguide,
  - Remaining half in cladding mode (exponential behaviour).

Coupling coefficient amplitude

Inside bandgap / **Outside bandgap**

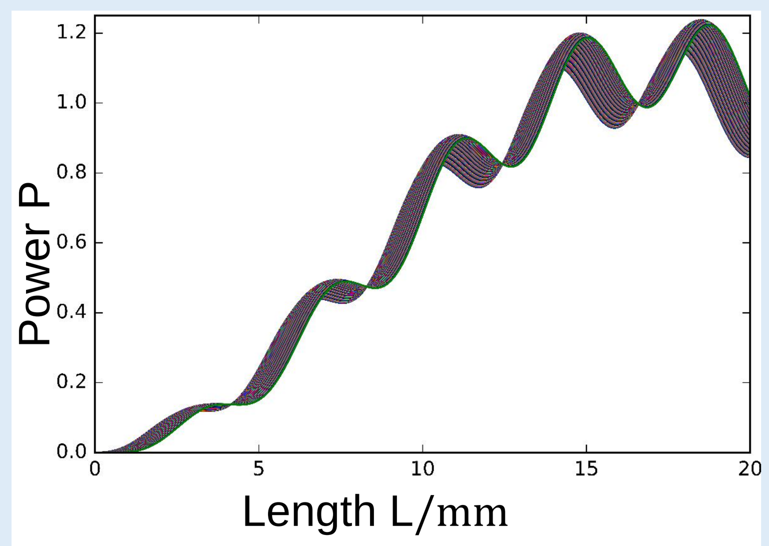


Solid – all modes
Dashed – three modes analytical

- Outside of bandgap, $\gamma_\pm = \pm i\Omega$ imaginary**:**
  - Oscillatory behaviour, beating between eigenfrequencies.
  - Cladding mode oscillates with frequency 2Ω.
  - Power transfer between waveguides approaches 100 %. Oscillation of lower frequency $\frac{\Delta K}{2} - \Omega$.

Selective transference of particular frequencies means that the device can be used as a wavelength division multiplexer (WDM).

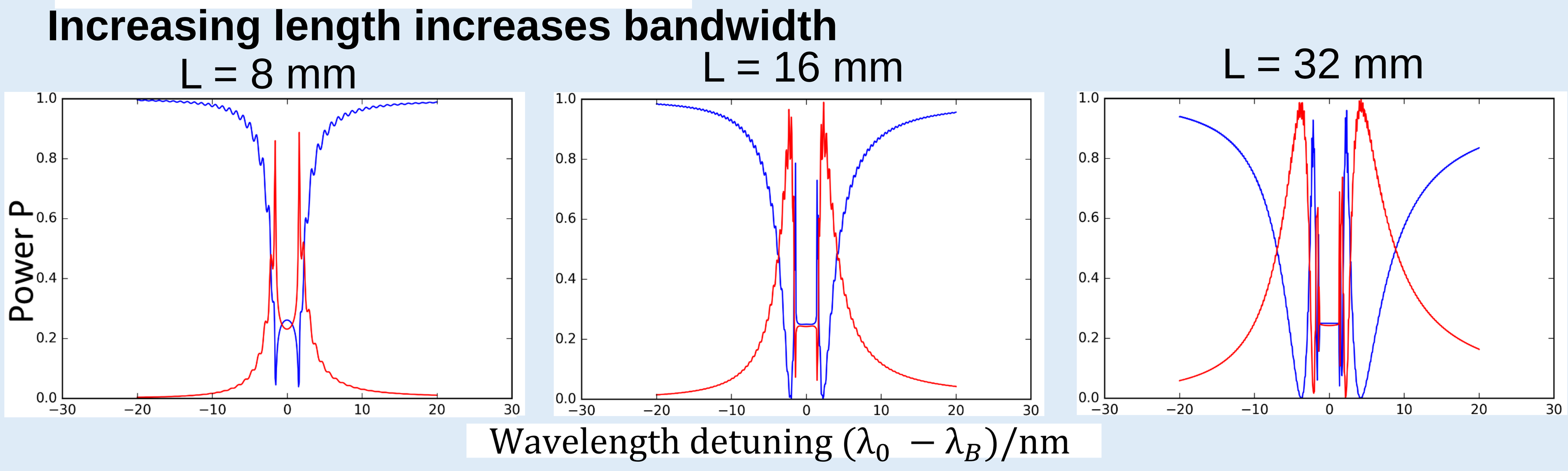
Power in top waveguide for different device lengths



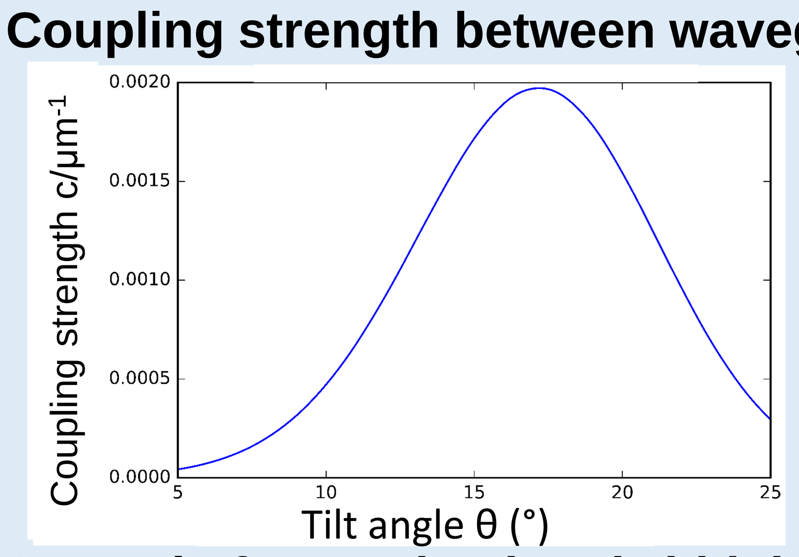
Top waveguide: points at which power does not depend on device length.

High fabrication tolerance with device length

Increasing length increases bandwidth



Coupling strength between waveguide and cladding mode vs tilt angle

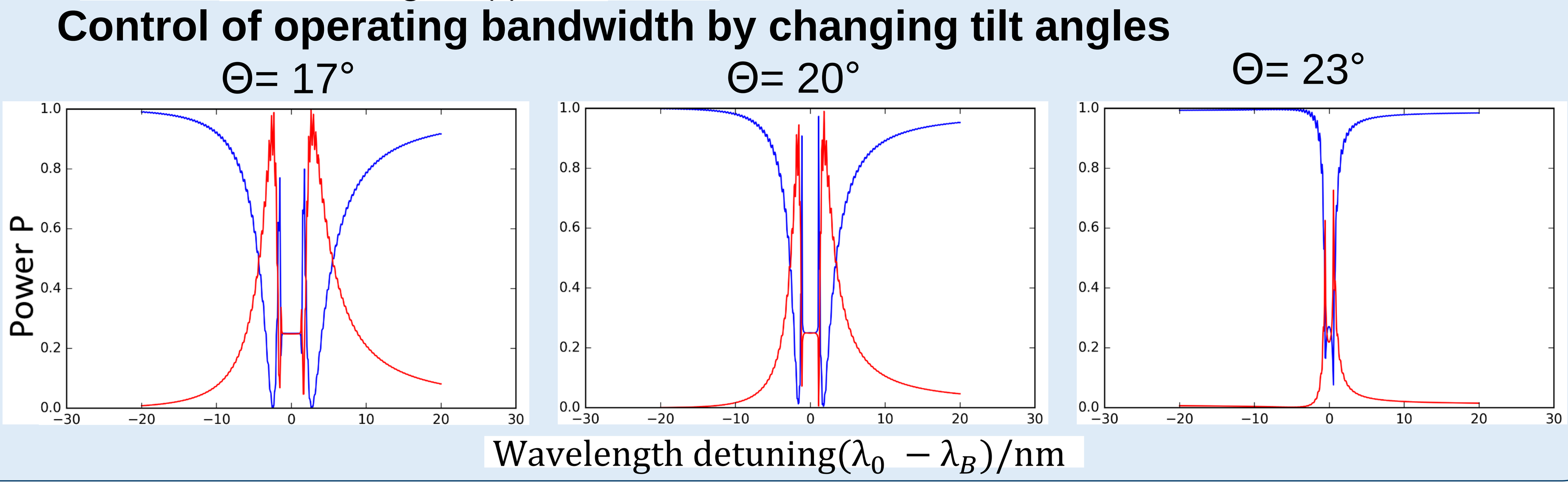


Peak at tilt angle expected by geometric optics.

Highest bandwidth at peak

That's why we need tilted gratings!

Control of operating bandwidth by changing tilt angles



Conclusions

We presented a new type of waveguide coupler that can couple light very efficiently between two waveguides. The use of tilted gratings allows for bandwidth control of the coupler which adds a new functionality in planar photonics. This could therefore be used as a flexible platform for the fabrication of new wavelength division multiplexers (WDM) or frequency filters.

[1] C. Sima et al., *Ultra-wide detuning planar Bragg grating fabrication technique based on direct UV grating writing with electro-optic phase modulation,* Optics Express, Vol. 21, 15747 (2013)
[2] M. T. Posner et al., *Integrated polarizing coupler based on tilted gratings,* In: Integrated Photonics Research, Silicon and Nanophotonics. Vancouver, Canada (2016)
[3] K. Okamoto, *Fundamentals of optical waveguides,* Elsevier, Amsterdam, second edn. (2008)