COMSOL CONFERENCE 2014 CAMBRIDGE

PHOTONICS RESEARCH GROUP

Birefringence Induced in Optical Rib Waveguides by Thermal and Mechanical Stresses

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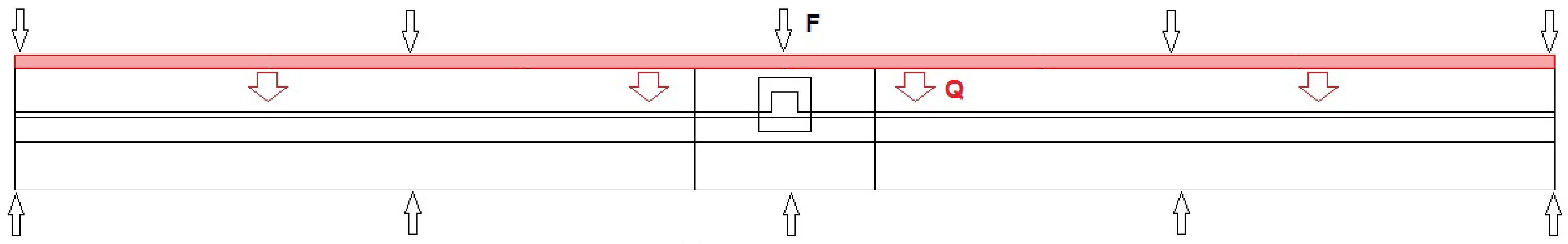
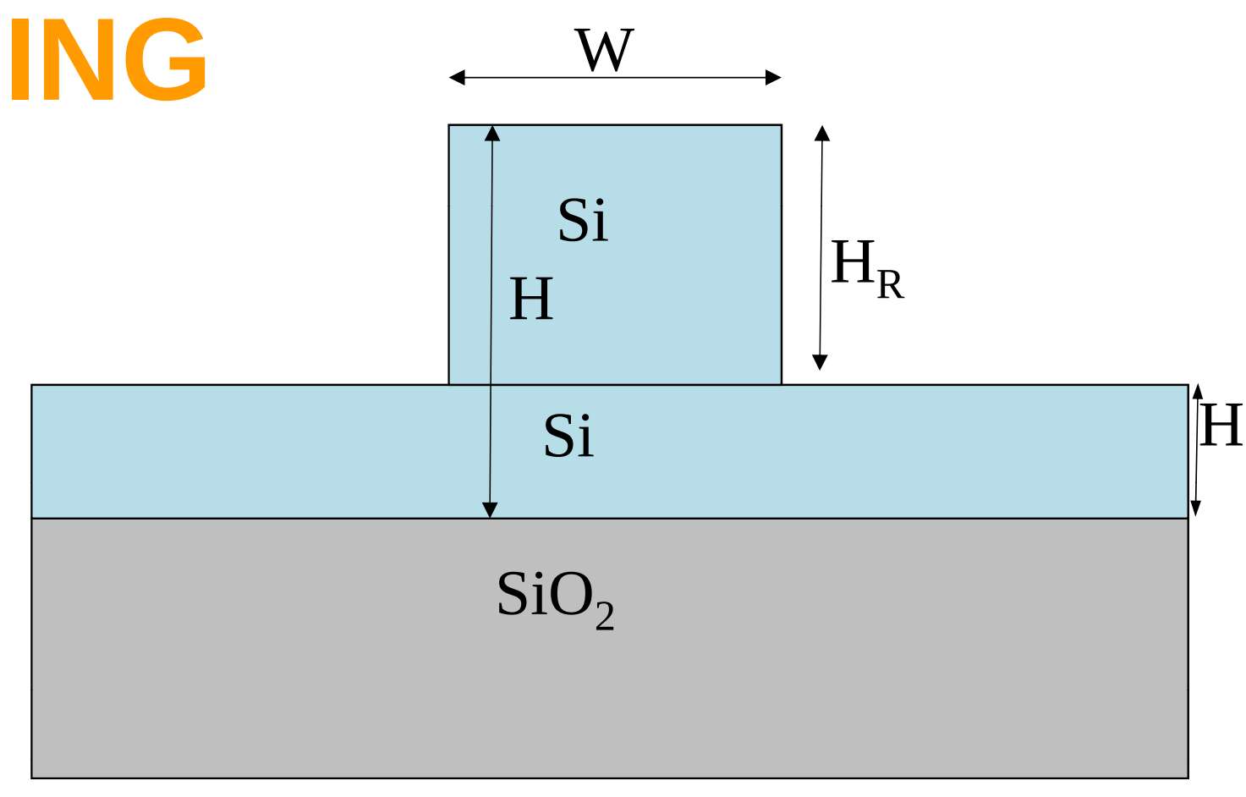
For decades, silicon has been considered the optimal material for electronics mass production. In the last few years, the possibility to realize highly performing active and passive photonic integrated devices using Silicon-on-Insulator (SOI) technological platform has been widely proved [1]. One of the most important aspects of any integrated optical technology for sensing or communication applications is the evaluation and control of the optical birefringence [2]-[3]. Generally speaking, the optical birefringence depends on the waveguide cross section, material and plasma dispersion effect [4], and mechanical stress. In this contest, a detailed study has been proposed in [5], demonstrating that the stress engineering can be considered an effective tool to modify or eliminate polarization dispersion in SOI waveguide device, for a wide range of waveguide cross-section shapes and sizes. In addition calculations and experiments proposed in [5] confirm that the SiO_2 cladding induced-stress can be used to eliminate the birefringence in SOI waveguides of arbitrary shapes for typical film stress values ranging from 100 to 300 MPa. Therefore, the goal of this work is to develop a self-consistent and integrated approach, in order to generalise the analysis presented in [5] including thermal and mechanical stress effects on guided-wave propagation in optical rib waveguides. In practical applications, a rib waveguide is often in contact with a surface at higher temperature that causes heat flow into the device: this results in material strain and, ultimately, in an optical birefringence. Besides, in many applications of such components, strain is also produced by a pressure that acts on the device. The situation is illustrated in Fig. 1 (a), where F is the force applied on the device and Q is the heat propagating into it. A silicon-on-insulator rib waveguide is in contact with an aluminum layer through a silica layer; the heat flow is caused by the heated aluminum layer whose temperature is higher than that of the rib. The aluminum layer also transmits the pressure on the component. The stresses applied to the waveguide material structure cause each mode to be rotated. Thus, in this paper we use Comsol Multiphysics™ [6] to obtain a fully integrated simulations of SOI waveguides in order to estimate the birefringence compensation.

SIMULATIONS BY MULTIPHYSICS MODELING



(a)



(b)

Figure 1 (a) Domain structure; (b) SOI waveguide cross-section.

THERMAL EFFECTS

$$\rho C\frac{\partial T}{\partial t}+\nabla\cdot\left(-k\nabla T\right)=Q$$

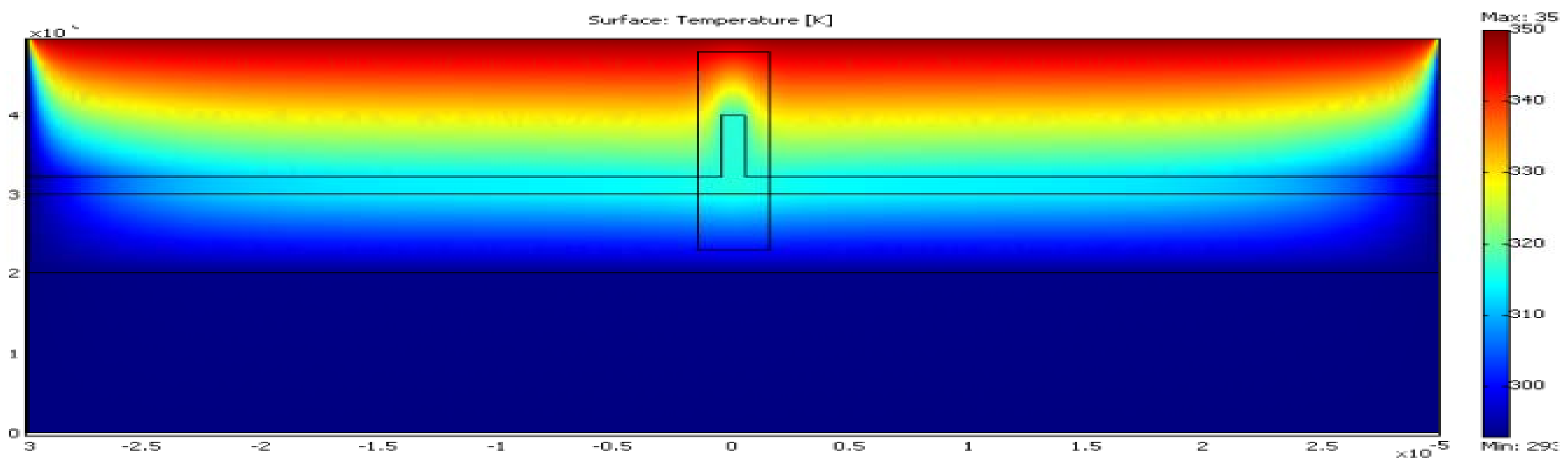


Figure. 2. Steady-state temperature distribution induced by aluminum layer at $T_{Al} = 350$ K.

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\end{bmatrix}=\frac{E_Y}{(1+\nu)(1-2\nu)}\begin{bmatrix}1-\nu & \nu & \nu\\ \nu & 1-\nu & \nu\\ \nu & \nu & 1-\nu\end{bmatrix}\begin{bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\end{bmatrix}-\frac{\alpha_{thermal}E_Y\left(T_{ridge}-T_{rom}\right)}{(1-2\nu)}$$

STRESS EFFECTS

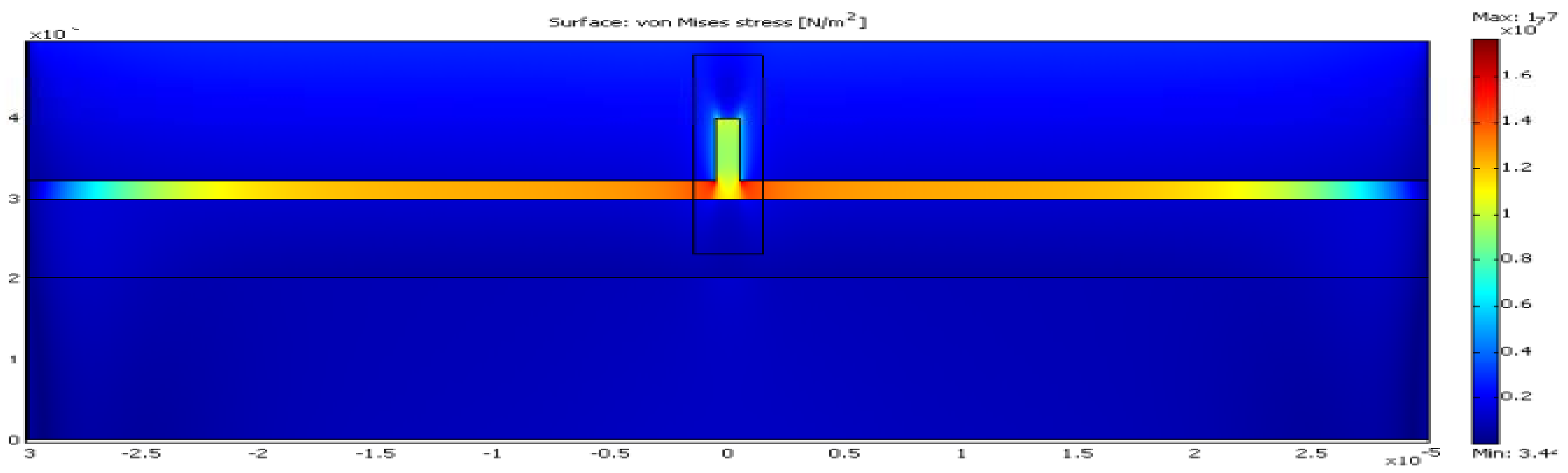


Figure. 3. Von Mises stress distribution for $T_{Al} = 350$ K and $F_y = 10^5$ N/m^2.

EM SIMULATION

$$\nabla_t\times\left(\varepsilon_{rczz}^{-1}\nabla_t\times\mathbf{H_t}\right)-\tilde{\varepsilon}_{rct}\nabla_t\left(\mu_{rzz}^{-1}\nabla_t\cdot\mu_{rt}\mathbf{H_t}\right)-\left(k_0^2\mu_{rt}-\beta^2\tilde{\varepsilon}_{rt}\right)\mathbf{H_t}=0$$

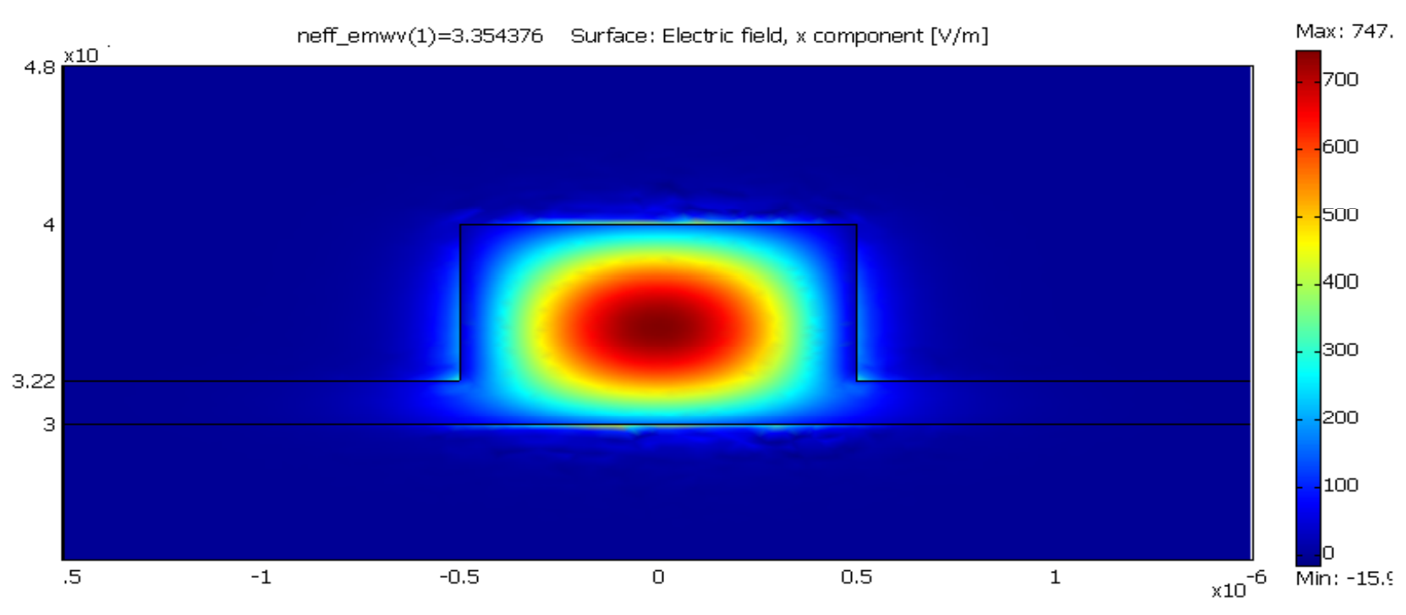


Figure. 4. x-component of electric field (quasi-TE mode) for $T_{Al} = 350$ K and $F_y = 10^5$ N/m² (Wg1).

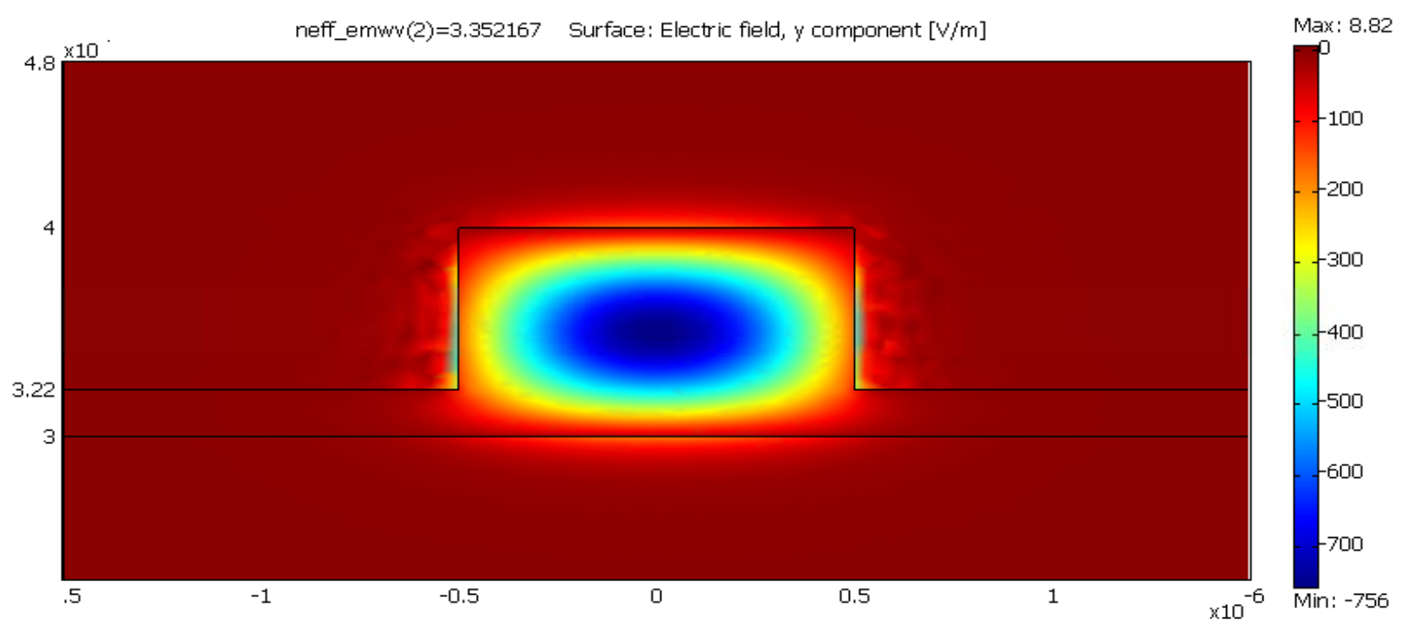


Figure. 5. y-component of electric field (quasi-TM mode) for $T_{Al} = 350$ K and $F_y = 10^5$ N/m² (Wg1).

NUMERICAL RESULTS

Wg1: $H_S = 0.22$ μm, $W = 1$ μm, $H = 1$ μm, $H_R = 0.78$ μm;

PARAMETERS	VALUES
Si Young's modulus, E_Y (Si)	170 (GPa)
SiO_2 Young's modulus, E_Y (SiO_2)	70 (GPa)
Si Poisson's ratio, (Si)	0.28
SiO_2 Poisson's ratio, (SiO_2)	0.17
Si linear thermal expansion coefficient, (Si) at 293 K	2.6×10^{-6} (K^{-1})
Linear thermal expansion coefficient, (SiO_2) at 293 K	0.5×10^{-6} (K^{-1})
Photoelastic coefficient p_{11}(Si)	-0.101
Photoelastic coefficient p_{12}(Si)	0.0094
Photoelastic coefficient p_{11}(SiO_2)	0.16
Photoelastic coefficient p_{12}(SiO_2)	0.27

Wg2: $H_S = 0.22$ μm, $W = 0.5$ μm, $H = 0.61$ μm, $H_R = 0.39$ μm.

$$\begin{cases}n_x-n_0=-B_1\sigma_x-B_2\left(\sigma_y+\sigma_z\right)\\ n_y-n_0=-B_1\sigma_y-B_2\left(\sigma_x+\sigma_z\right)\end{cases}$$

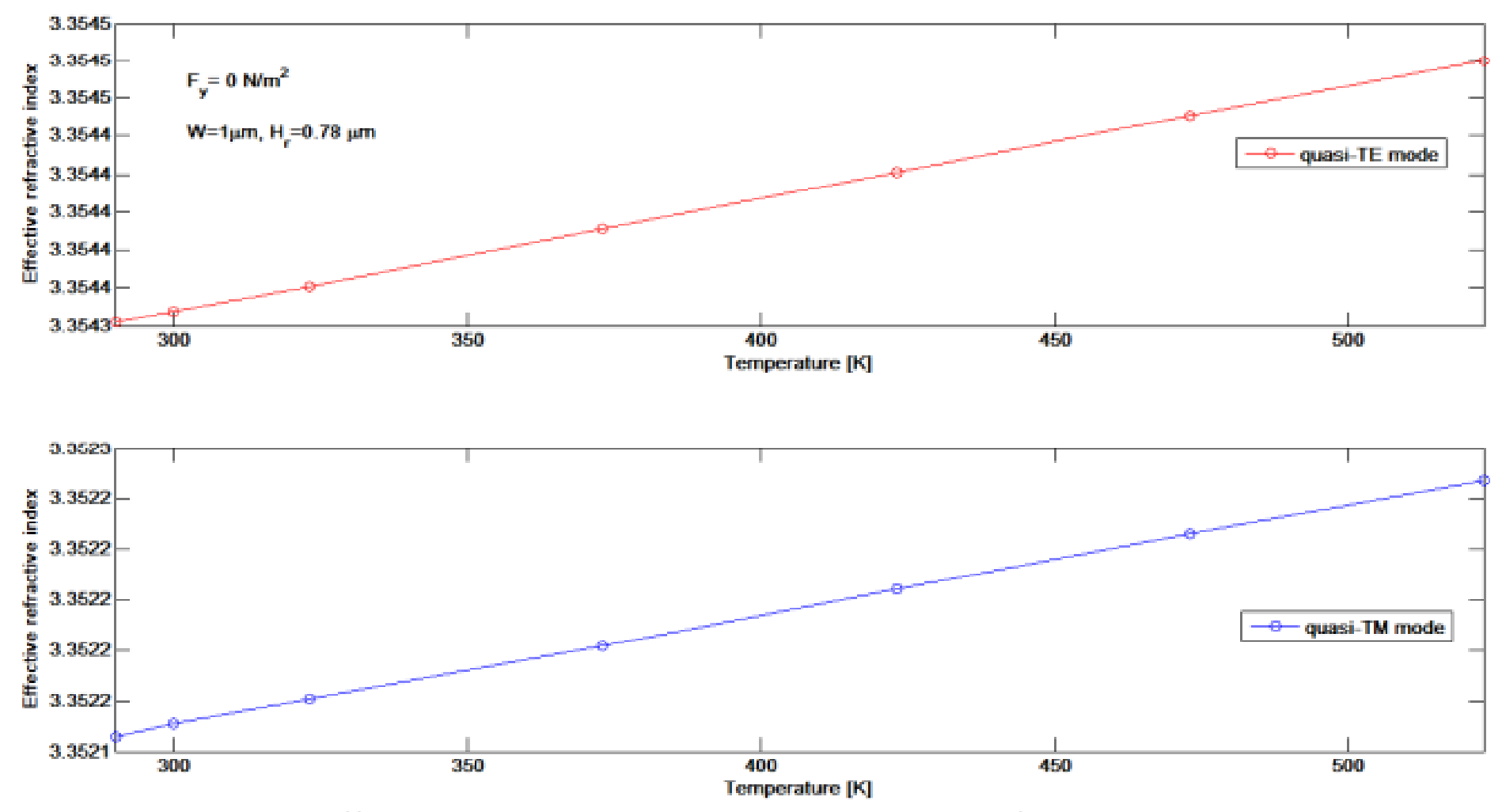


Figure. 6. Effective index versus temperature for quasi-TE and quasi-TM modes (Wg1).

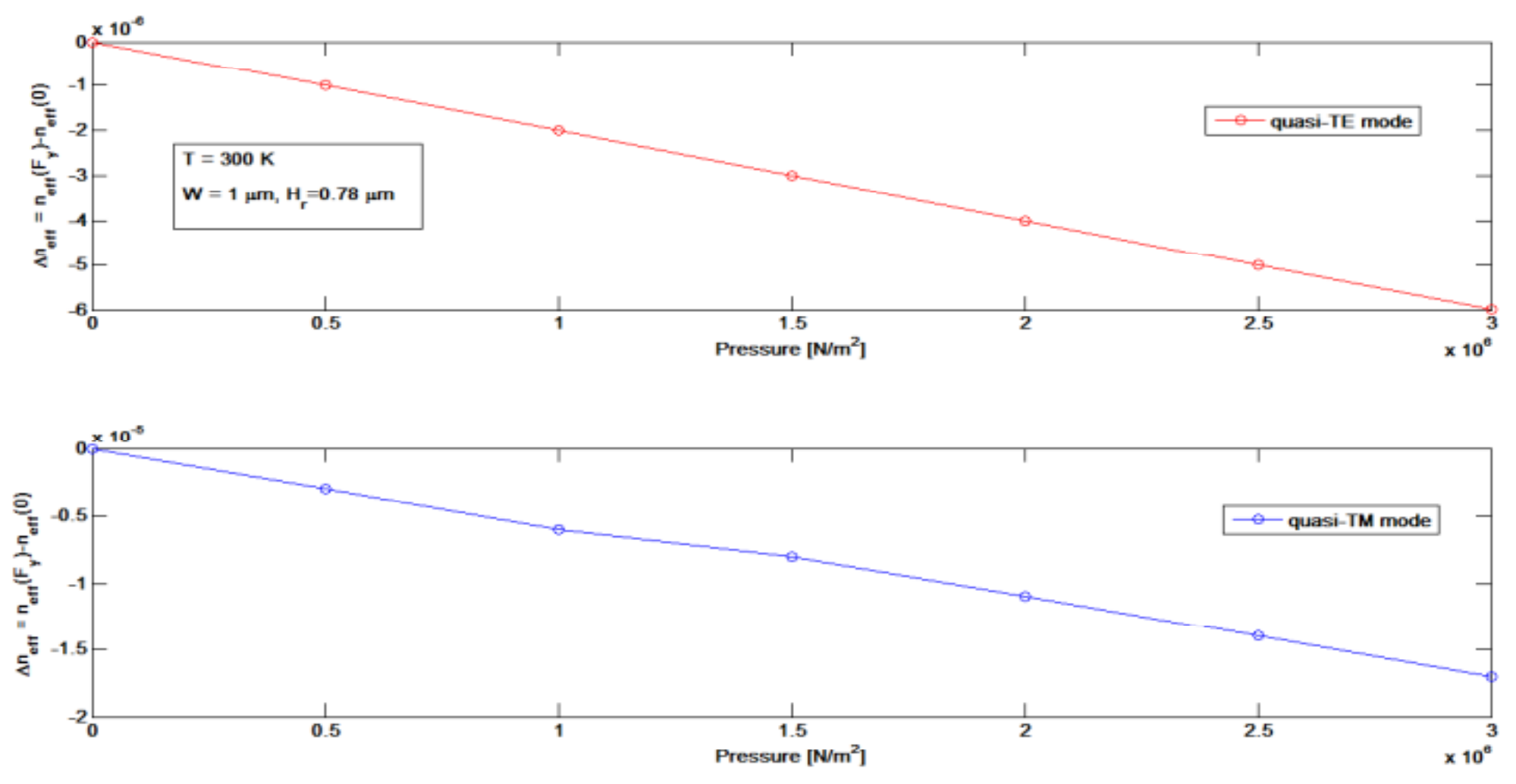


Figure. 7. Effective index versus applied pressure for quasi-TE and quasi-TM modes (Wg1).

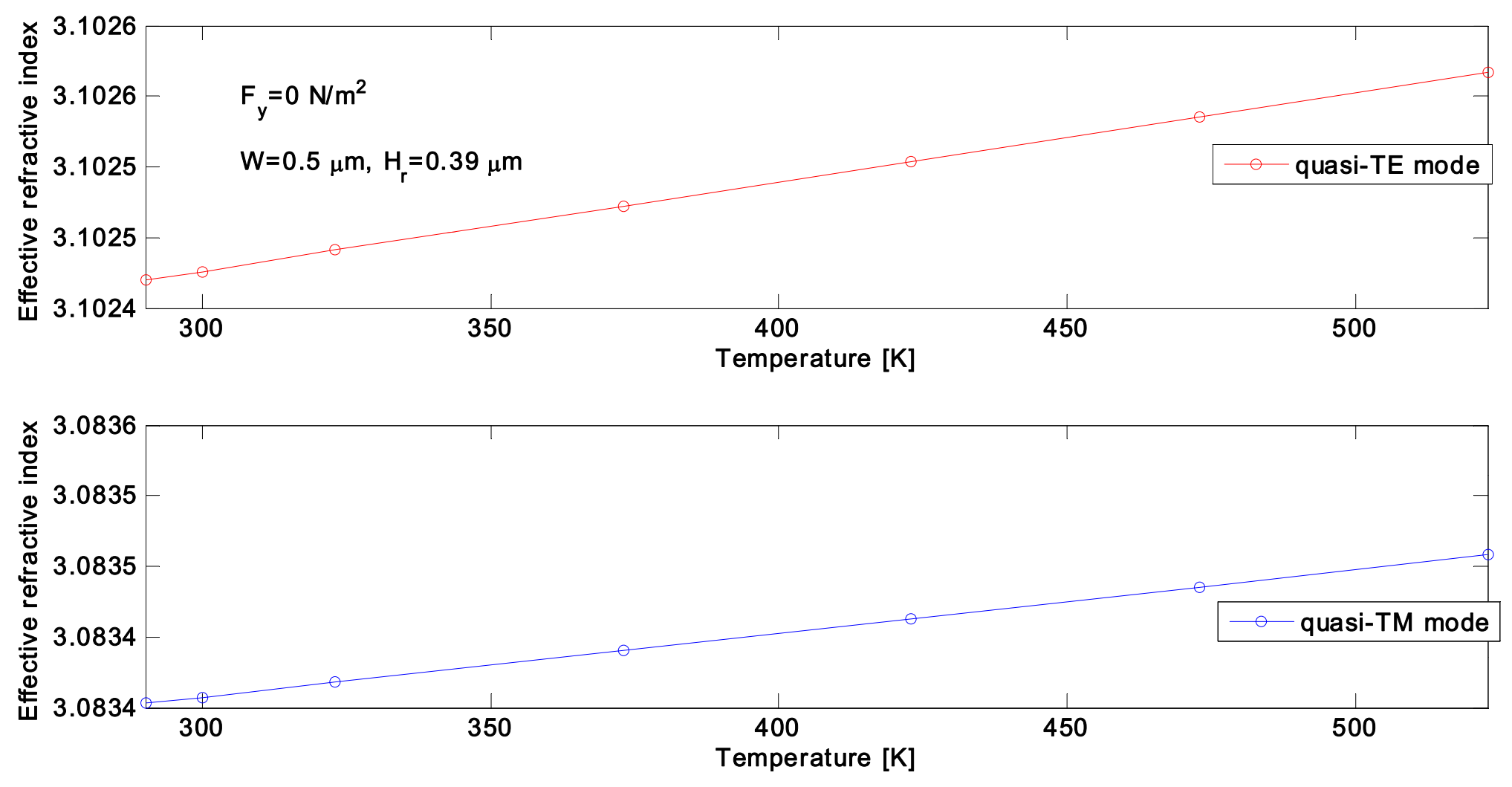


Figure. 8. Effective index versus temperature for quasi-TE and quasi-TM modes (Wg2).

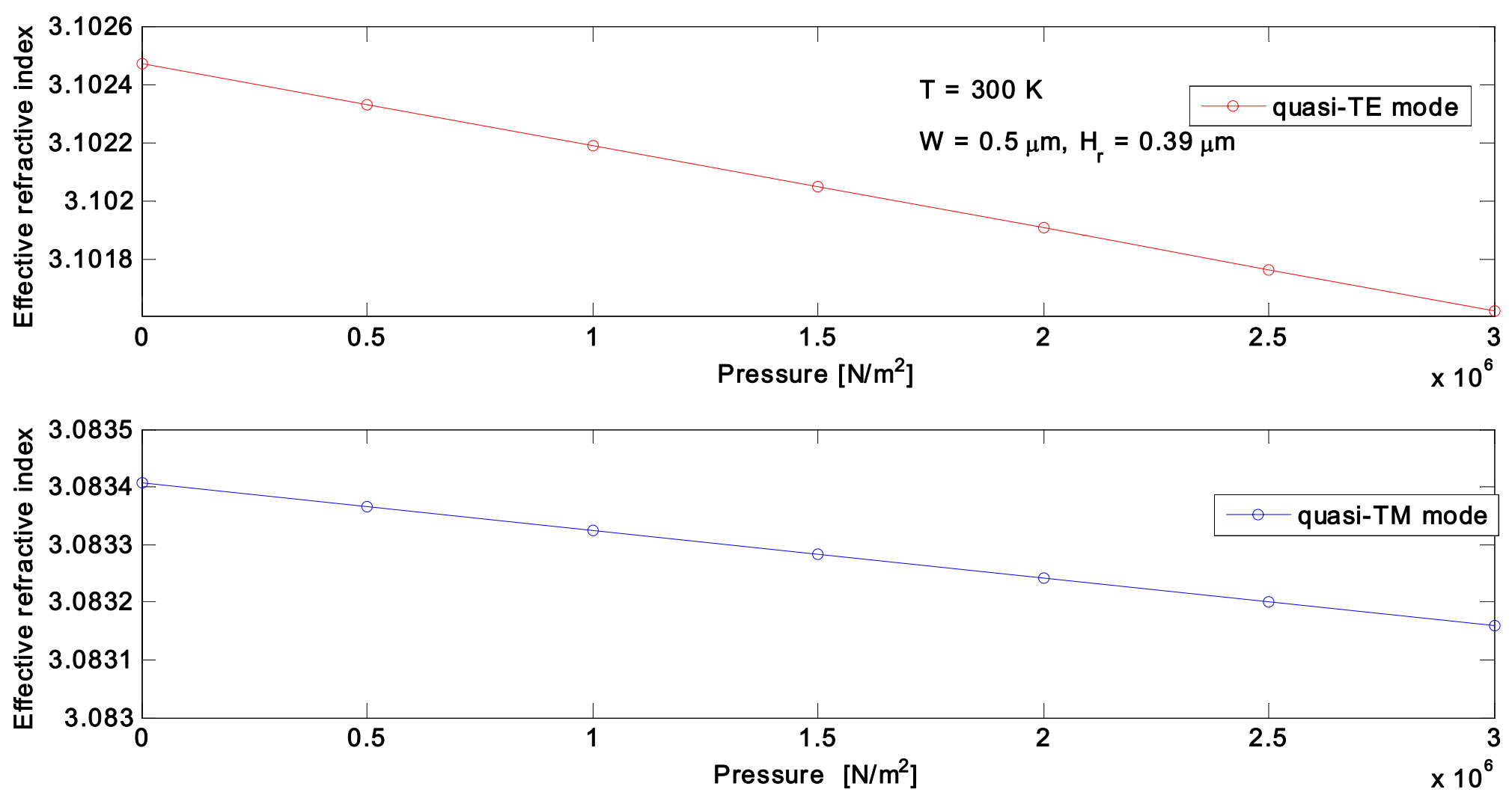


Figure. 9. Effective index versus applied pressure for quasi-TE and quasi-TM modes (Wg2).

Conclusions

In this work a fully integrated multiphysics model, involving heat transfer, mechanical stress and electromagnetic modules, has been used for SOI waveguides. Physical effects induced by heating and external pressure acting on the device have been investigated. Effective refractive index changes for quasi-TE and quasi-TM optical modes have been calculated for SOI waveguides with micro and nano-scale cross section. Through this calculation, a thermal and pressure slope has been estimated in order to realize an useful tool for the optical design of optical waveguides under different temperature and pressure conditions.

References

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6. Comsol Multiphysics, ver. 3.2, *single license* (COMSOL Inc., Stockholm, Sweden), 2005.

Excerpt from the Proceedings of the 2014 COMSOL Conference in Cambridge