Influence of Annealing for Enhancing Second-Order Nonlinearity in Strained Silicon

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Abstract

Second-order optical nonlinearity can be induced in silicon (Si) by breaking the crystal symmetry with a straining layer [1,2]. The influence of annealing for enhancing the nonlinearity by means of a silicon nitride (SiN) layer is investigated. The annealing process has been simulated taking into account different begin temperatures to room temperature. Furthermore, the influence of the intrinsic stress and thickness of the SiN layer has also been analyzed. To start with, SiN deposited on top of a Si substrate was considered and the stress when crossing the interface was obtained. Figure 1(a) shows that the stress in the Si ($y > 0$) is zero and increases in a small layer around the interface to the intrinsic stress 1.2 GPa of the SiN ($y < 0$). Whenever an annealing step is performed, both the stress in the Si and in the SiN increases, but the increase in the SiN is larger than in the Si. Therefore, a higher begin temperature of annealing leads to higher stress around the interface. Next, a figure of merit (FOM) has been defined as the normalized overlap integral over the waveguide core between the electric field intensity and partial derivatives of the strain components, since the value of this FOM will be proportionate with the induced nonlinearity. The dimensions of the waveguide (height = 220 nm, width = 400 nm) were optimized in previous work [3]. From the simulations, it was found that the FOM for TE was ten times larger than the one for TM, therefore only the TE is considered here. Figure 1(b) shows the FOM as a function of the begin temperature of annealing for a SiN-thickness of 500 nm and 700 nm. In the latter, the FOM is slightly larger than in the former, although the difference is quite small. We also see that an annealing procedure starting from a higher temperature leads to a higher FOM and therefore to a larger non-linearity. In Figure 1(c), the FOM is plotted as a function of begin temperature of annealing for a 700 nm SiN-layer, but the intrinsic stress of this layer is changed from 1.2 GPa (as before) to 10 MPa and to -1.2 GPa. The case of 10 MPa shows the same behaviour as the case of 1.2 GPa, but the FOM is significantly smaller. For -1.2 GPa, the FOM at room temperature is equal to the 1.2 GPa case, but performing an annealing step leads to a lower FOM. As a conclusion, a combination of annealing and compressive intrinsic stress of the SiN layer will be beneficial to enhance the induced second-order optical nonlinearity in silicon.

References

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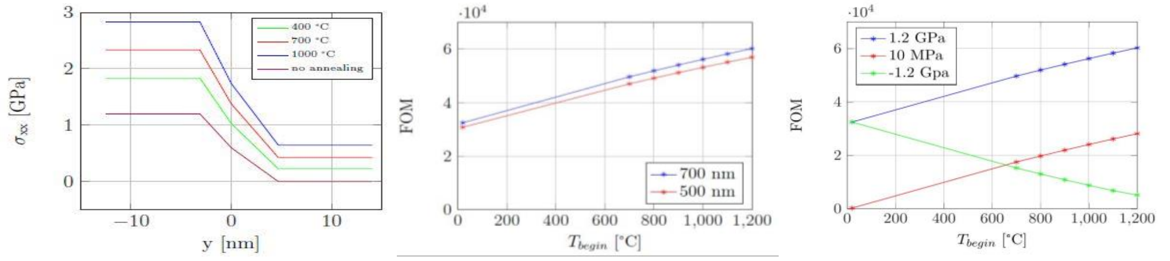
[3] I. Olivares, T.I. Angelova, E. P.-Cienfuegos, P. Sanchis, SPIE Photonics Europe, Brussels (Belgium), 2016.

Figures



(a) (b) (c)

Figure 1.- (a) Stress xx as a function of distance perpendicular to the interface for no annealing, 400°C, 700°C and 1000°C (from bottom to top), (b) FOM as a function of begin temperature of annealing for 500 nm and 700 nm SiN –layer, (c) FOM as a function of begin temperature of annealing for different intrinsic stresses of the SiN.