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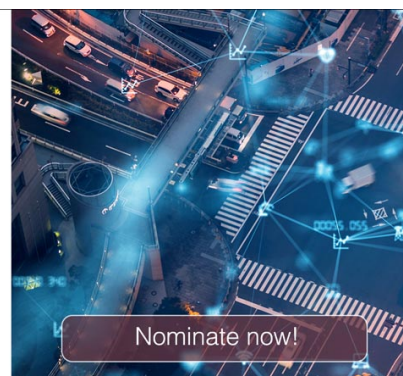


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Properties of GaN optomechanical nanobeam cavity

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Abstract. Gallium nitride based nanobeam cavity system was theoretically analysed by using finite element method-based model. Optical and mechanical resonant localized modes structure of the nanobeam cavity was calculated. Depend on the geometrical properties there were found modes with high quality factor for the both cases. The maximum optical quality factor reaches value $5 \cdot 10^4$ in cavity with value $d = 90nm$.

1. Introduction

Optomechanics is a growing scientific area that explores the interaction between the mechanical motion and the localized electromagnetic fields [1]. A number of phenomena such as cooling the mechanical mode to the ground motion state open new possibilities and applications concepts [2]. The aim of the many types of research is to find the optimal condition for high-quality eigenmodes localized in the same cavity area. One of the classes of such systems is a freestanding semiconductor system with etched holes of peculiar geometry. It may be noted a "zipper" cavity [3] and nanobeam cavity [4, 5] due to their high optical quality factor and low effective mass. One of the most promising semiconductors in many application areas is a gallium nitride (GaN). It's optical (emission bandgap and refractive index) and mechanical (Young's modulus) properties are close to the widely considered materials for optomechanics such as diamond. However, GaN material is easier to work with in structures fabrication process (like etching of holes in nanobeam cavity). Also, recent studies demonstrate the possibility to fabricate complex GaN structure with peculiar geometry and high crystallography quality even without etching [6, 7]. Recently a design of nanobeam cavity optimized to GaN material and operating in UV spectral area [8] was demonstrated.

In the present study, we considered a quasi-1D GaN nanobeam cavity and theoretically analyzed the localization of both mechanical and optical eigenmodes in such system with a variety of geometrical parameters.

2. Results and discussion

Nanobeam cavity represents the strip of 170 nm width, fixed at both ends. The strip usually placed above the slit in the substrate. Elliptic holes in strip define the properties of the system to localize both optical and mechanical waves. Scheme of the nanobeam cavity shown in figure 1(a). Optimization of the geometry and size of the hole in the nanobeam cavity is a topic for multiple kinds of research in this area [4, 5].



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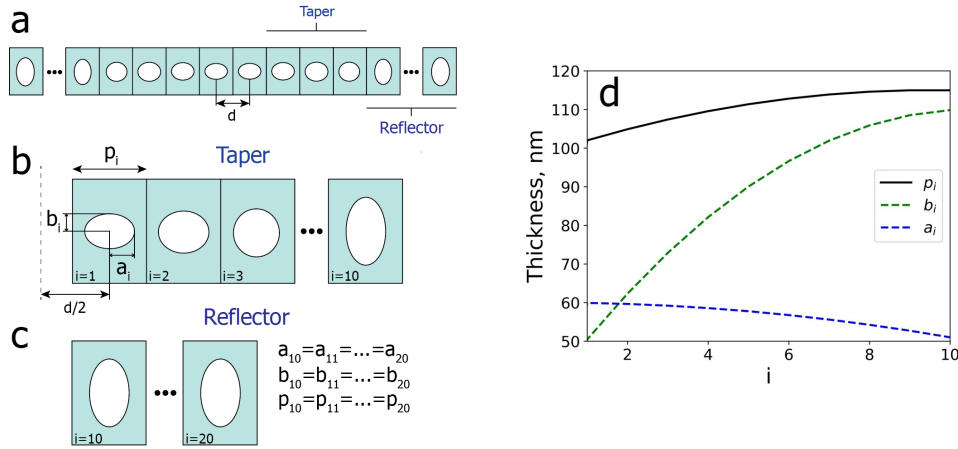


Figure 1. (a) Scheme (top view) of the GaN nanobeam cavity and detailed geometrical properties of cavity parts: taper (b) and reflector (c). The distribution (squared) of the nanobeam cavity parameters in the taper region (d).

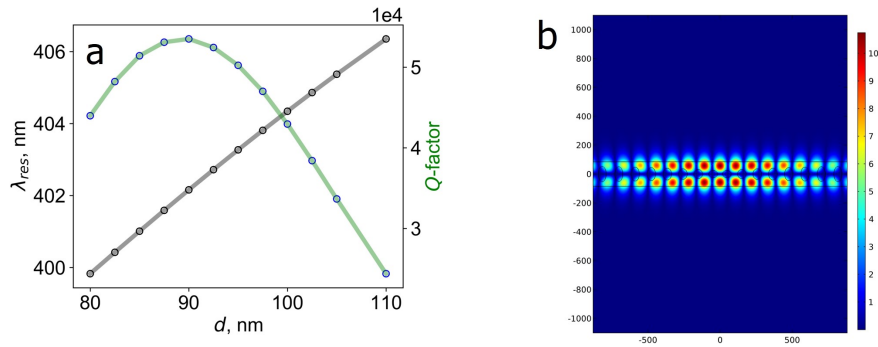


Figure 2. (a) Optical mode resonance wavelength dependence on the distance between two central holes parameter (left axis) and the quality factor dependence (right axis). (b) Electric field distribution (V/m) of optical eigenmode ($\lambda = 402$ nm, $Q = 5.3 \cdot 10^4$) for the cavity with $d=90$ nm.

There are two main parts of the cavity: a taper (figure 1(b)) and a reflector (figure 1(c)). The taper region (10 holes) defined by the three parameters: a_i , b_i , p_i . There p_i - the period of the element, a_i and b_i - elliptic hole parameters and d - the distance between two central holes. Those values depend on position by the quadratic function (figure 1 (d)) as in [5] for the optimal operation of the system in the near UV (≈ 400 nm) region. Size parameters for a reflector region is the same for all holes and equal to a_{10} , b_{10} , p_{10} . The distance between two central holes d allow tuning the resonant wavelengths in both optical and mechanical cases.

The model was based on a finite element method (FEM), that allow calculating eigenfrequencies and both optical mode and mechanical displacement distributions in structure. Perfect electric conductor boundary conditions around the nanobeam cavity area were used to calculate optical eigenstates (GaN refractive index was chosen as 2.55). Mechanical eigenmode problem was solved by the two-dimensional model with fixed ends of the strip (GaN Youngs modulus is 330 GPa).

Results are demonstrating high optical quality factor states supports in the considered system. Figure 2 shows the results of the optical case simulation. A number of modes were found, but

only one has maximally localized in the cavity central region. Dependence of the modes quality factor on the distance between central holes (d) shown in figure 2 (a). There are maximum at $d = 90\text{nm}$ corresponding to the $Q = 5.3 \cdot 10^4$ at $\lambda = 402\text{ nm}$. Electric field distribution is shown in figure 2 (b). Figure 3 shows the spectral position dependence on the value of the d for the high localized mechanical modes. Insets show the displacement field for the symmetric (blue curve) and the antisymmetric (green curve) localized modes. It can be seen, that operation frequency can be widely tuned by variation of the parameter d ($\sim 0.4\text{ GHz}$ for the 10 nm) .

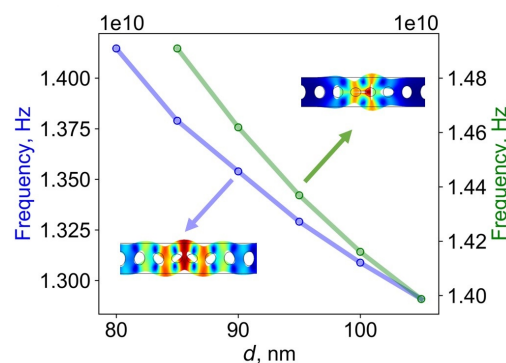


Figure 3. Mechanical mode resonance wavelength dependence on the distance between two central holes parameter. Mechanical displacement fields of the symmetric (12.8 GHz) and antisymmetric (14.9 GHz) modes are shown in the insets.

3. Conclusions

Results demonstrates significant localization of optical and mechanical modes inside the considered system. Dependence of mechanical and optical eigenstates spectral position on the geometrical parameter was demonstrated. The maximum optical quality factor reaches value around $5 \cdot 10^4$ in cavity with $d = 90\text{ nm}$.

Acknowledgments

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