High electric field enhancement in THz regime using a gold-nanoslit filled with Lithium Niobate oxide

S. Bagiante[1], F. Enderli[2], J. Fabianska[2], I. Vartiainen[1], H. Sigg[1], T. Feurer[2]

[1]Laboratory of Micro- and Nanotechnology
Paul Scherrer Institut
Villigen 5232, Switzerland
Fax: + 41 563102646; email: salvatore.bagiante@psi.ch
[2]Institute of Applied Physics
University of Bern
Bern 3012, Sidlerstrasse 5, Switzerland
Fax: +41 31 631 89 13; email: thomas.feurer@iap.unibe.ch

Abstract

In this paper the THz response of a nanoslit gold array fabricated on a Lithium Niobate Oxide ($LiNbO_3$) substrate is studied. Theses structures have been fabricated with a small gap, filled by $LiNbO_3$. These structures exhibit an electric field enhancement (FE), which is comparable with the measurement performed on silicon substrate using the same slit width. Good overall agreement between theoretical and experimental results is obtained.

1. Introduction

The research in THz light sources and THz applications has been constantly growing during the last 15 years. However, the generation of THz radiation with high efficiencies makes still many technical difficulties and, therefore, it is largely unexplored. The electric field enhancement is of crucial importance due to the present technological limitations in the peak fields obtainable from current sources [1]. These sources limit the realization of nonlinear THz experiments [2]. These limitations can be overcome by using *metamaterials,* which can create an enhancement of the electric field in the THz regime [3].

In this work the results concerning the development of a nanoslit array with different periodicity and with a nano gap of 130nm, using $LiNbO_3$ as substrate are shown. Moreover, a new fabrication process enabling nanoslit filled by $LiNbO_3$ is presented. Using a THz near-field imaging technique and conventional far-field spectroscopy, together with numerical simulations, the nanoslit has been investigated.

2. Results

Seo et al. [4] have shown that a single nanoslit in a thin gold film act as a *nano-capacitor.* The incident radiation induces a current flow on the metal surface that leads to an accumulation of charge carriers in the gap region. This capacitive charging in turn may result in an in-gap enhancement of the electric field by several orders of magnitude. Shalaby et al. [5] achieved large enhancements together with high transmission in slit-arrays, by carefully adjusting slit width and periodicity. For an array of

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40 nm wide slits with 100µm periodicity a peak near-field enhancement factor of 760 at 0.2 THz, corresponding to 30% transmission has been demonstrated [5].

In our approach, a $LiNbO_3$ substrate with corrugated mesas was fabricated by e-beam patterning and oxide etching. The mesas feature a trapezoidal shape, where the small base is 260nm and the height is 60nm, c.f. the scheme shown in Fig. 1a). In Fig 1b) a SEM image (top view), taken after the mesas fabrication, is reported.

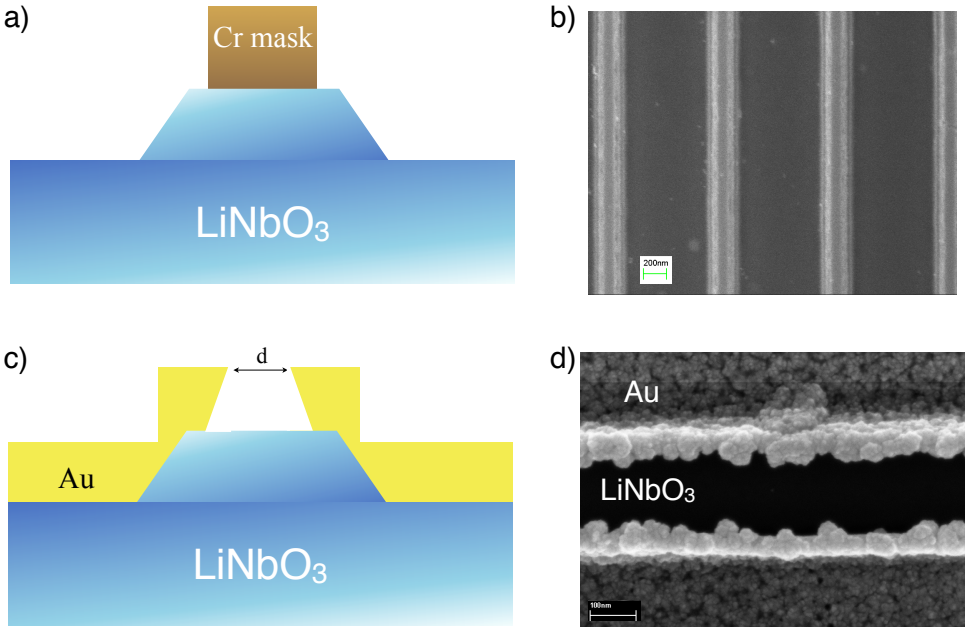

Fig. 1: a) Schematic of our LiNbO3 substrate after the etching process and related SEM image (top view) in b); c) Schematic of our sample after the gold deposition and the related SEM image (top view) in d).

After the definition of the mesas, a small layer of 20nm of gold is evaporated. A lift-off process has removed all excess of metal. Finally, using an electroplating deposition system, we reach the final Au thickness of 60nm. With this fabrication process the final width (d) of the slit is 130nm, as shown in Fig. 2c) and 2d).

Simulations of these structures have been performed using a numerical modelling based on the finite element method (FEM) provided by commercial software (Comsol). For discretization, a triangular or tetrahedral variable mesh size is used, which allows to work with a refined mesh at the metal-dielectric interface. The frequency-dependent simulation is applied to determine the electric field enhancement in the nano-slits array filled by $LiNbO_3$ as a function of frequency. This approach has the advantage that the dispersive metal properties are included using a complex conductivity, for example, through a Drude model for the metal gold [6]. From the frequency-dependent simulations, we determine the field enhancement factor as reported by Merbold et al. [7]. All calculations have been performed considering that the on-substrate case is deduced from the free-standing case if the frequency axis is scaled by a factor of $n^2_{eff} = (n^2_{LiNbO3} + n^2_{Air})/2$ [5].

In Fig. 2 the experimentally obtained field enhancement factor in the spectral range 0.1 – 1 THz, along with FEM simulations for the slit array on substrate, are shown. Preliminary comparisons of the experimental data with the numerical results show a difference between the measurements and the simulations when the slits on the $LiNbO_3$ substrate are considered.

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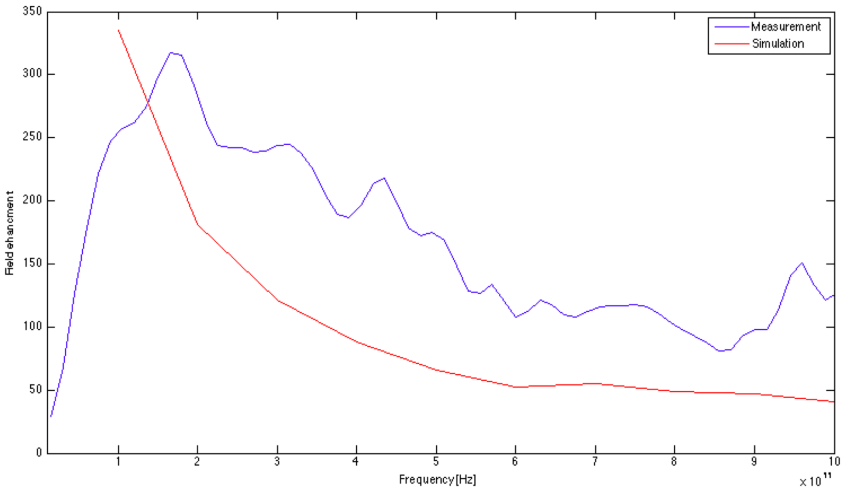

Fig 2: Simulated enhancement factor for a single slit array on $LiNbO_3$ substrate (red line), and the average field enhancement obtained from the measurement (blue line).

These differences are due to the difficulty to extract from the measurement the field enhancement factor. The value of our electric field enhancement extracted from the experiment has been scaled to match the theoretical data. The calculation of the field enhancement from the experimental data is still open, due to the difficulty to compare it whit the simulations.
From our measurements the real slit length is 0.5mm, while the diameter of our THz beam is larger then 1mm. This effect produces a cut-off frequency of 120 GHz. This frequency value explains why the field enhancement drops below that frequency. The maximum enhancement at 0.2THz is about 330, using a single slit with a gap of 130nm, as show in Fig 2.

3. Conclusion

In conclusion, we have investigated Au nanoslit using filled by $LiNbO_3$. We have demonstrated experimentally that a 130 nm wide single slit shows enhancement factor of 330 at 0.2 THz and a corresponding transmission to 30% is deduced. Such substrates, combined with an intense THz source, open the way to new types of nonlinear THz experiments.

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