Taming Extraordinary THz Transmission through Sub-λ Slot Arrays via Array Truncation, Slot Rotation, Polarization and Angle of Incidence

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***Abstract*—Accurate and time-effective simulation and design optimization of quasi-optical (QO) systems is an extremely challenging electromagnetic problem given the multi-scale dimension of QO components and the need to consider the finite size of such components to account for effects like diffraction. To show that the Method of Moments (MoM) provides an elegant solution for these problems, truncated rectangular arrays of tilted slots are measured in a QO Terahertz (THz) time-domain setup and comparison with MoM is carried out. The extraordinary transmission peaks are modulated by the size of the array and the orientation of the slots with respect to the incident electric field.**

I. INTRODUCTION

EXTRAORDINARY transmission (ET) through metallic periodic structures with unit cells showing high degree of symmetry has been studied experimentally [1]-[5] and theoretically [6]-[8] for decades now, paving the way for applications. At optical frequencies, ET has been widely exploited for sensing applications [9], whereas at millimeter-wave and THz frequencies, it has been proposed for quasi-optical components [10]-[12] and for metamaterials [13],[14].

Reducing or removing symmetries as well as truncating the array can result in a more structured spectrum, which has only recently attracted some attention [15]-[18]. Here, we experimentally show how an array of tilted slots (45 degrees with respect to the in-plane periodicities) can display quite a dramatic change in the spectrum depending on the truncation of the array, the polarization of the THz signal and the angle of incidence. This comprehensive study is supplemented with a Method of Moments (MoM) analysis [17],[19] to unveil the origin of the observed spectral features.

II. RESULTS

Several samples of varying number of slots along the *y* direction (N_y) were fabricated by laser machining (see Fig. 1) and characterized using an all fibre-coupled THz time-domain spectrometer TERA K15 following the methodology described in [16],[18],[19] for collimated configuration. The excitation pulses had temporal lengths of at least 260 ps in all measurements, resulting into a spectral resolution of 4.8 GHz. The in-plane periodicities were 540 μm and 600 μm, and the slot dimensions were 226 μm and 176 μm with ±5 μm according to the microscope analysis.

We first studied the angle of incidence dependence of the samples. The sample-rotation analysis of the 61 row sample reveals that the relative transmissivity of the two ET peaks (associated to each of the periodicities) is modulated by the choice of polarization. TE oblique incidence (Fig. 1) favors the lower frequency resonance, while the TM oblique incidence (not shown) enhances the higher ET resonance [20]. This effect is explained by the increasing wavevector matching between the impinging and the leaky-wave supported by the array.

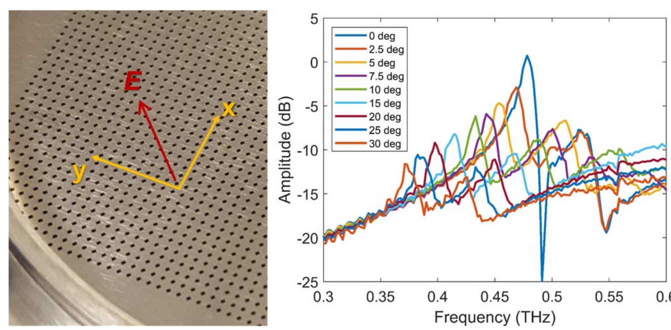

Fig. 1. Picture of the N_y = 61 sample (left) and on-axis transmission for varying rotation along *E*-axis (right); *E*-field is perpendicular to the slot long side.

The excitation of the leaky-waves, and thus, the ET peaks, associated with the two in-plane periodicities can be controlled by the array truncation and by rotating the sample along the optical axis (i.e. *z*-axis), see Fig. 2. The amplitude of the ET peaks increases with the number of rows until it saturates, as shown for symmetric subwavelength hole arrays [16] and subwavelength slit arrays [19]. Meanwhile, the higher frequency ET linked to the *x*-axis in-plane period can be suppressed when the illumination is polarized along the *y*-axis.

The study of the on-axis transmission at normal incidence in terms of short-time Fourier transform (i.e. spectrogram) for samples with increasing N_y [20] unveils the two channels contributing to the ET peaks: the direct transmission that shows a flat response with frequency across the whole spectral window 0.3 to 1 THz, and the leaky-wave-mediated transmission that results in a long-lasting energy ringing in time only at the ET frequencies.

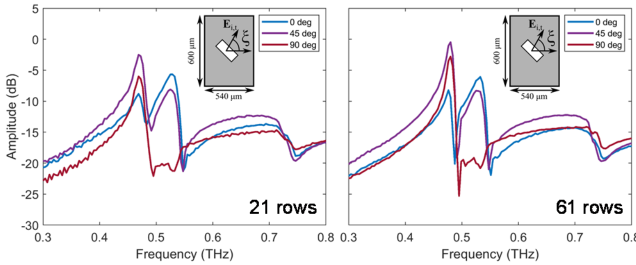

Fig. 2. Measured on-axis transmission for different rotation of the N_y = 21 (left) and N_y = 61 (right) samples along the *z*-axis as indicated in the top inset.

Both, the sample-rotation and spectrogram analysis are explained by the dispersion relation of the samples calculated with the MoM [17],[20]. Using the same MoM implementation, the wavevector dependence of the peaks is explained by calculating the complex wavevector dispersion relation for the leaky-waves involved, showing a rich anti-crossing phenomena of the two modes supported by the structure, as presented in Fig. 3.

This study opens the door to novel QO devices that exploit the mixing of the many leaky modes allowed by the absence of symmetries in the array, which are in turn highly selective because of the resonance nature of the ET mechanism.

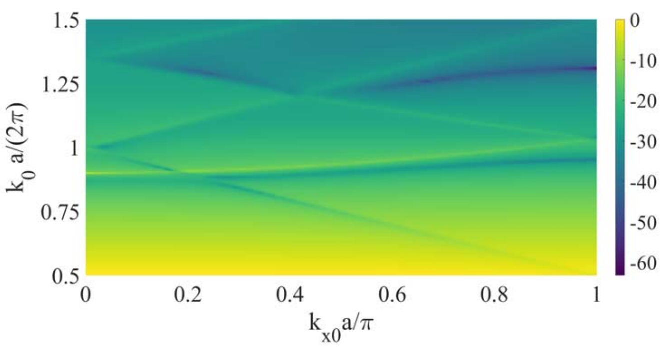

Fig. 3. Cut of the complex dispersion relation for the leaky-waves supported by the non-truncated array of tilted slots, obtained in terms of the determinant of the MoM matrix in logarithmic scale. The minima (black) represent the eigen-solutions of the MoM, while the bright spots represent the lightlines of the different diffraction orders.

III. Summary

We have shown that breaking the symmetry of the unit cell (slot orientation and dissimilar in-plane periodicities) yield a complex transmission spectrum. The comprehensive campaign of THz measurements has been supplemented with Method of Moments results to unveil unambiguously the origin of findings.

Acknowledgements

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