Double Effective Band-Pass Submm-Filters Based on Anisotropic Resonant Meshes

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***Abstract*—We present the results of development of original band-pass filters for 4-channel radiometric diagnostics of hot plasma in the frequency range 260-400GHz. The filters constitute multilayer interference structures consisting of specially designed thin anisotropic 2D resonant metal meshes separated by polypropylene layers 150-170 microns thick. Due to anisotropy of meshes the transmission band position of the filters strongly depends on polarizations of the incident radiation. It enables to use only two filters for realizing a 4-channel spectral system that reduces costs of its production. Numerical simulations of frequency response of developed filters are compared with the results of their characterization at a submillimeter BWO-spectrometer. The technological aspects of filter fabrication are described.**

I. Introduction And Background

METAL mesh structures with subwavelength topology of two-dimensional mesh cells is a well-known and effective approach for solving problems of quasi-optical filtering of radiation from a microwave to IR spectral region. The choice of appropriate design of mesh cells, number of meshes in an interference structure and intermesh distances allows one to synthesize a filter with a desired frequency response [1].

It should be noted that meshes with isotropic mesh pattern are commonly used in filters as isotropy results in insensitivity of the mesh frequency response with respect to polarization of incident radiation that is reasonable for work with unpolarized radiation sources and polarization insensitive detectors. On the other hand, for multichannel spectral systems where polarized beams and polarization sensitive detectors are used it is more effective to employ mesh filters with anisotropic meshes. Mesh anisotropy allows one to realize a shift of a filter’s operating frequency band for mutually orthogonal polarization components of the incident radiation and thereby to use only one mesh structure instead of two for separating two cross-polarized frequency channels. This feature is attractive for multichannel quasi-optical spectral systems since it reduces costs of system fabrication.

In this report we present the results of development of band-pass metal mesh filters for application in a 4-channel spectral diagnostics of 260–400 GHz emission from hot and turbulent plasma in the GOL-3 multimirror open magnetic trap heated by a relativistic electron beam [2]. The diagnostics includes four polarization sensitive Shottky-diode based submillimeter detectors with matched horn-lens antennas and three polarizing 1-D grids (beamsplitters) for demultiplexing of the input radiation beam. The multilayer interference band-pass filters based on anisotropic resonant meshes of two different designs considered below are employed for frequency filtering of demultiplexed cross-polarized beams propagating in four differentt spectral channels.

II. Design of Filters

For selecting four separated frequency bands within the spectral region 260–400 GHz we have designed two types of anisotropic resonant meshes with spaced dipole slot elements which parameters are shown in Fig. 1. In comparison with frequently used resonant meshes with crossed dipole slots [1] the spaced slot elements reveal a narrower band-pass response. Ansoft HFSS v.11 electromagnetic software was used for optimization of single mesh parameters by optimizing transmission of double-mesh and triple-mesh filters consisting of identical 0.5μm-thick Al-meshes embedded into polypropylene (PP), which was chosen as a supporting substrate material due to its low loss tangent and dispersion and good technological properties. Conditions of maximal single filter peak transmittance for X- and Y-polarizations simultaneously at minimal FWHM and ~35GHz frequency shift of adjacent frequency channels were used in the optimization procedure. PP thickness was chosen to be

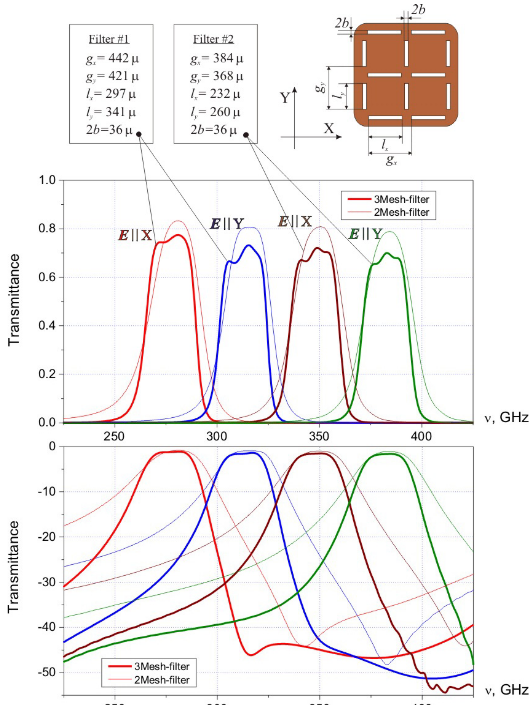

Fig.1. Geometry of used anisotropic meshes and theoretical frequency response of 2-mesh and 3-mesh filters.

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150μm for inter-mesh layers and 300μm for outer layers that satisfied $\langle\lambda_{res}\rangle/4n$ - and $\langle\lambda_{res}\rangle/2n$ - impedance matching conditions respectively (here $\langle\lambda_{res}\rangle$ is an averaged resonance maximum wavelength, n is the refractive index of PP: $\langle\lambda_{res}\rangle\approx0.9$mm, $n\approx1.5$). The results of numerical simulations of transmittance for optimized filters are presented in Fig.1. Comparison of 2- and 3-mesh filters shows that at theoretical FWHM ~25GHz the latter ones provide much steeper edges of the transmission curves and higher (20-40dB) adjacent band isolation however its maximum transmittance is lower due to higher losses.

III. Filter Fabrication and Characterisation

At the present stage of experimental development we have manufactured and tested two sets of 2-mesh filters that differ in used PP-layers thickness and fabrication methods. For the first set a photolithography technique was employed for creating the anisotropic mesh pattern of the aforementioned topology on the surface of single high-quality metallized PP-films 40μm thick. We used PP films with decreased melting temperature (~140^0C) that allowed us to apply a relatively cheap technology of hot lamination for fabricating 2-mesh filters of the following configuration: 8x40μmPP–Mesh–4x40μmPP–Mesh–8x40μmPP. Simulation showed that it is admitted to neglect the effects connected with small increase (10 and 20μm) of total thickness of PP-layers filling inter-mesh and mesh-air gaps in comparison with the values of 150 and 300 μm respectively used in initial theoretical simulations.

For the second set of 2-mesh filters a photolithographic pattern was created on the opposite sides of a single monolithic PP-layer 170μm thick forming a filter with the configuration Mesh–170μmPP–Mesh. No lamination procedure was employed for these "cheap and fast" filters as we used cheap moderate-quality PP with nominal melting temperature ~170^0C that is too high for direct multilayer structure fusion in a hot lamination machine.

For characterization of manufactured filters the submillimeter BWO-Spectrometer "Epsilon" [4] developed in A.M. Prokhorov General Physics Institute (Moscow, Russia) was used. Due to high monochromaticity ($\Delta f/f \sim 10^{-5}$) and absolute output power of tunable BWO source of polarized radiation such a spectrometer allows one to realize broadband spectral measurements at high (~10^4-10^5) spectral resolution and dynamic range without cryogenic techniques. In general, measurements demonstrated satisfactory selective properties of manufactured filters (Fig.2). For the samples from the set #1 it was revealed ~65%-broadening of transmission curves along with ~45% drop in peak transmittance that is explained by uncontrollable deviation of mesh parameters from the nominal values during a hot lamination process. For the "cold" filters from the set #2 the "theory-experiment discrepancy" is much smaller however the loss tangent value of the used 170μm-PP-film derived from comparison of the theory and experiment appears to be significantly higher ($tg\delta\approx0.025$) than for purer PP used in filters from the set #1 ($tg\delta\approx0.001$). In the future we plan to improve the quality of output submillimeter-wave metal mesh filters by mastering the technique of controllable vacuum hot pressing using high-quality pure PP-film substrates.

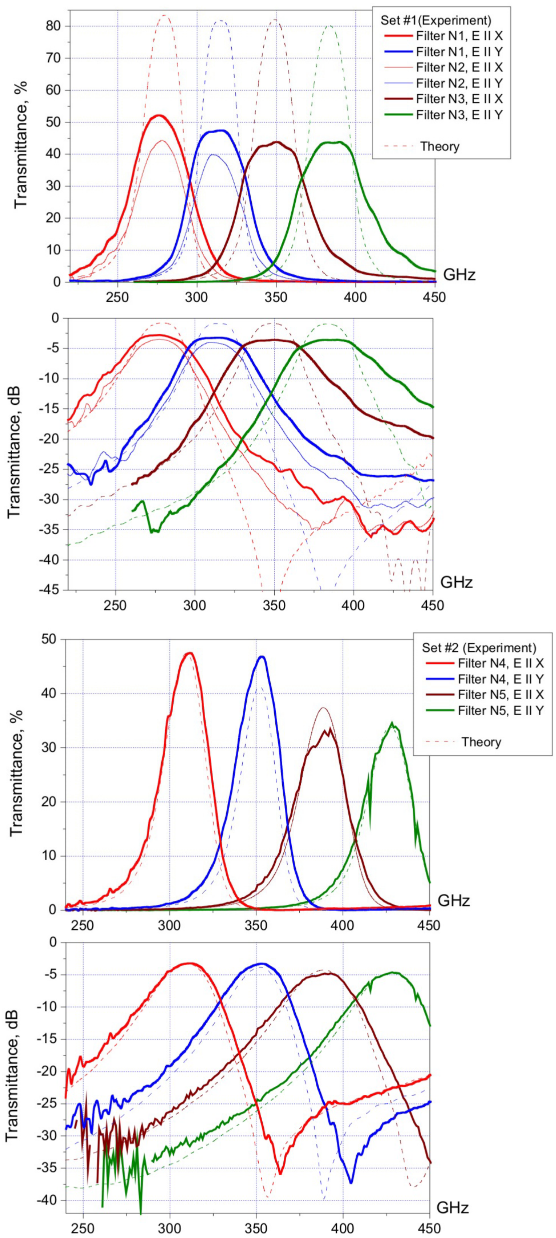

Fig.2. Frequency response of manufactured 2-mesh filters.

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