Multilayer dielectric diagonal horn for reshaping THz QCL beam pattern

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We present the development of a diagonal dielectric horn in order to improve the beam shape of THz quantum cascade lasers (QCL). A high resistivity (HR) silicon based diagonal horn which consists of 7 pyramidal grades has been designed and the working frequency is 2.7 THz. The HR-silicon based substrate integrated image guide (SIIG) [1] (cross-sectional size: 80 μm x 14 μm) is used to guide the EM energy from a metal-metal 1st-order QCL (cross-sectional size: 50 μm x 14 μm) to the seven-layer horn. The mode in SIIG and QCL is E_{11}^{y} mode and TM_{00} mode, respectively. The simulated insertion loss of the SIIG is ~ 0.10 dB/mm at 2.7 THz. The loss induced by the SIIG is then relatively low considering its small dimension (length ~ 240 μm). Full wave EM simulations of the dielectric horn have been performed and we have obtained the beam diagram with a reduced FWHM and a near Gaussian shape. To ease handle and transfer, the handling structures around the horn are applied, as shown in Fig. 1.

The fabrication process is novel and challenging. Since it is impossible to pattern the complex 7-layer 3D mask using traditional photo-lithography or electron-beam lithography, two-photon lithography technology is used to form the mask for the 3D pyramid-shape diagonal horn. First, we built a perfect 1:1 photo resist (PR) mask, as shown in Fig.1. The deep reactive ion etching (DRIE) is then performed to transfer the mask to HR-silicon wafer. The next fabrication plan is transferring the photoresist pattern to a ~900 nm-thickness silica, and using the silica as the etching mask for silicon etching. The fabrication process is similar to [2]. The fabrication is in process now.

Compared to the traditional silicon lens or the micro-transverse-electromagnetic-horn antenna [3], the proposed dielectric diagonal horn is much more compatible with planar circuit integration and with the GaAs based QCL fabrication process. Moreover, the micromachined silicon based multilayer horn can be easily scaled up to higher frequency QCL applications.

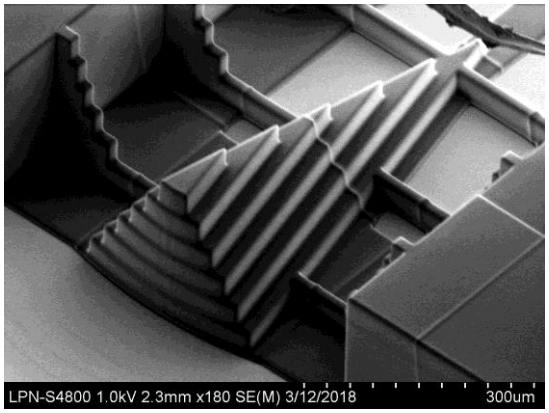

Fig. 1. Fabricated 1:1 PR mask of the pyramid-shape diagonal horn.

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NOTES:

REFERENCES

[1] A. Patrovsky and K. Wu, "Substrate integrated image guide (SIIG)- a planar dielectric waveguide technology for millimeter-wave applications," *IEEE Trans. Microw. Theory Tech.*, vol. 54, no. 6, pp. 2872–2879, Jun. 2006.

[2] C. Jung-Kubiak, *et al.*, "A multistep DRIE process for complex terahertz waveguide componets," *IEEE Trans. THz Sci. Technol.*, vol. 6, no. 5, pp. 690–695, Jun. 2016.

[3] W. Maineult, "Metal-metal terahertz quantum cascade laser with micro-transverse-electromagnetic-horn antenna," Appl. *Phys. Lett*., 93, 183508. 2008.