A low voltage, ultra-compact plasma spectrometer

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Design

Motivation

The measurement of ion energy spectra in space has increasingly focused on understanding the energy flow and coupling between different spatial regions through simultaneous measurements of essential plasma parameters, e.g., magnetic field, electric field, density, and temperature. Spatially resolved measurements are critical for understanding the electrodynamics of different parts of the magnetosphere. The next step in multi-spacecraft missions is to go well beyond missions consisting of a handful of large and sophisticated spacecraft to missions comprised of large numbers of simple micro or pico-spacecraft. On flying hundreds of spacecraft and thereby obtaining simultaneous, high spatial resolution plasma measurements over a significant fraction of the entire magnetosphere will be possible to understand the energy flow and coupling between different magnetospheric regions. However, the current generation of plasma spectrometers are too massive, consume too much electrical power, and require too much assembly and testing time to be flown on future multi-spacecraft microsatellite missions. Advanced water scale fabrication techniques naturally lend themselves to relatively high manufacturing volumes, lower mass, lower costs, and therefore change the paradigm for dealing with flaws or defects in individual instruments.

Test were performed using the variable energy electron beam in the Space Plasma Instrumentation Facility at Goddard Space Flight Center of 1) a collimator, 2) a single energy analyzer layer with one band biased, and 2) a collimator-energy analyzer bonded assembly with five bands biased to the same voltage. Results from the first two tests were successful. Results from the third test demonstrated several challenges to consider.

Figure 7. Microchannel plate detector image of the electron flux passing through two regions of a collimator. The collimator regions are rectangular and the beam flux is largest in the center of the collimator region (a result of the beam having a few degree divergence and thus only the collimator region in the center of the beam is fully illuminated).

Figure 8. Transmission through both collimator regions as a function of horizontal tilt angle in the electron beam calibration facility. The solid/dashed lines are Gaussian fits to the measured transmissions.

Manufacture

Collimator

100 mm diameter, 320 µm thick, <100> crystalline axis orientation, heavily P/Boron doped (resistivity < 0.005 Ω-cm) silicon wafers
Two wafers stacked to achieve desired ±2º x ±2º angular acceptance
Deep reactive ion etching (DRIE) processing to fabricate collimating apertures of 28 µm × 28 µm with 40 µm center-to-center spacing
Narrowing of holes to 17 µm ± 17 µm observed
Design transparency of 44% but narrowing reduces to 20%

360 mm thick <100> heavily P/Boron doped (resistivity < 0.005 Ω-cm) silicon on a 200 µm thick layer of <100> P/Boron doped (resistivity > 1,000 Ω-cm) silicon with 2 µm thick buried oxide layer
DRIE processing of 60 µm width plates with 80 µm plate-to-plate spacing
Undercutting of plates (as seen in Figure 5 c) required us to increase plate width from design of 10 µm to reallized width of 60 µm. This increased overall length of instrument from 1 cm to 1.75 cm
Plate spacing and thickness yield an active aperture area of 27%

Figure 2. Energy analyzer layer.

• Consists of 8 bands of 10 curved channels (9 plates).
• Original design has 300 µm high plates that are 10 µm thick and separated by 80 µm. (Revised to 60 µm thick plates after initial manufacturing tests).
• This layer can be seen as the entrance to the left side of the energy analyzer (EA) and exit from the right side.
• The large electrodes between the bands of curved plates provide electric contact points for individual biasing of the curved plate bands.
• A pattern of 100 V, 0 V, 50 V, 75 V, 25 V, 62.5 V, 87.5 V, 0 V, and 25 V creates energy passbands of 20 keV, 10 keV, 2.5 keV, 7.5 keV, 12.5 keV, 17 keV, and 15 keV, respectively.

Integrated single layer device

New design concept integrates collimator and energy analyzer onto the same wafer.
• Reduces requirement for separate fabrication and alignment steps.
• Increased densities in laboratory plasma applications (e.g., magnetic fusion edge plasma and processing plasmas) enable adequate single in a single-layer energy analyzer with reduced height. This enables the collimator structure to consist of 60 µm by 60 µm bars aligned with each of the energy analyzer entrance apertures, providing 100% transmission efficiency.
• We are working on designs to enable integration of the collimator and energy analyzer that will still achieve adequate signal for the lower densities in space plasma applications.

Figure 3. (a) A single layer energy analyzer with an integrated collimator structure. (b) Expanded view.

Figure 6. Detector electronics board with SSSD mounted in the center.

Energy Analyzer

Detector

Silicon solid state detector (SSSD)
Manufactured by Craig Tindall at Lawrence Berkeley National Laboratory
Thinned contacts provide lower threshold energy of 2 keV for electrons (Keesee et al., 2008)
Four pixel detector and electronics have been assembled and will be tested in electron beam chamber at WVU during Summer 2016.
Custom SSDS with 8 pixels (as seen in Figure 1) and ASIC-based electronics will be developed for flight instrument.

Future Work

We are in the present year of our current NASA H-TiDES grant, at the end of which we expect to be at a Technology Readiness Level (TRL) of 3. We are seeking funding to continue development to bring the instrument to a TRL of 6. The next steps include:
• Design, manufacture, and test integrated collimator-energy analyzer
• Manufacture and test multi-layer stack
• Test SSDS in current configuration
• Develop ASIC-based electronics for 8-pixel SSDS
• Consider detector options for lower-energy populations (e.g. ionsphere)
• Flight test components
• Manufacture complete spectrometer prototype