Next Generation ECE Imaging: Status and Plans for TEXTOR

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***Abstract*—Advances in array technology coupled with a simplified optical design have resulted in significantly expanded plasma coverage and enhanced sensitivity, while simultaneously reducing the LO power levels required to pump the imaging mixer array. Details of the next generation plasma imaging concept, with particular emphasis of the redesigned TEXTOR ECE Imaging system, are provided.**

I. Introduction And Background

ELECTRON cyclotron emission (ECE) imaging (ECEI) is a plasma visualization technique employed to study the dynamics of electron temperature T_e fluctuations. ECEI collects broad bandwidth millimeter wave ECE radiation and uses large aperture optics to image it onto a 1-D planar mixer array to form 2-D T_e fluctuation images [1-7]. Advances in array technology coupled with a simplified optical design have resulted in significantly expanded plasma coverage and enhanced sensitivity, while simultaneously reducing the LO power levels required to "pump" the imaging mixer array. Details of the next generation plasma imaging concept, with particular emphasis on the redesigned TEXTOR ECE Imaging system, are provided.

II. The Mini-Lens Array Concept

The ECEI mixer arrays employ dual dipole antennas printed on a thin dielectric substrate, together with a large (90-120 mm diameter) hyper-hemispherical substrate lens shared by all antennas. The primary purpose of the substrate lens is to reduce surface wave losses by reducing reflections at the air-dielectric interface. Using a single large substrate lens common to all antennas, however, makes it difficult to feed local oscillator (LO) power to the off-axis elements through the substrate lens because the lens shapes and refracts each antenna element differently.

Supplying LO power from the air side of the antenna rather than the substrate side simplifies the LO optics; however, there exist three distinct disadvantages. The first is that the antenna is more sensitive to radiation from the dielectric side than from the air side. The second is that the air side antenna pattern is considerably broader than the dielectric side due to the focusing properties of the substrate lens, thereby making the LO pumping less efficient. The third, and by no means the least important, is that the resonant frequency of the antenna differs considerably between the two sides. Due to a lack of high power LO sources at millimeter-wave frequencies, ECEI systems to date employ antennas resonant with the air side LO in order to make full use of the limited LO power levels at the cost of reducing the dielectric side RF sensitivity.

A new imaging array concept involves the use of an array of miniature elliptical lenses or mini-lenses (one per antenna; see Kong *et al*., these proceedings). The elliptical lens is designed to refract rays originating at its focus so that they emerge parallel to each other [8]. Figure 1 shows one such mini-lens array, consisting of 16 miniature elliptical lenses placed in a horizontally-staggered arrangement to reduce the inter-element vertical spacing between the lens centers (and thereby reduce the inter-element spacing in the plasma).

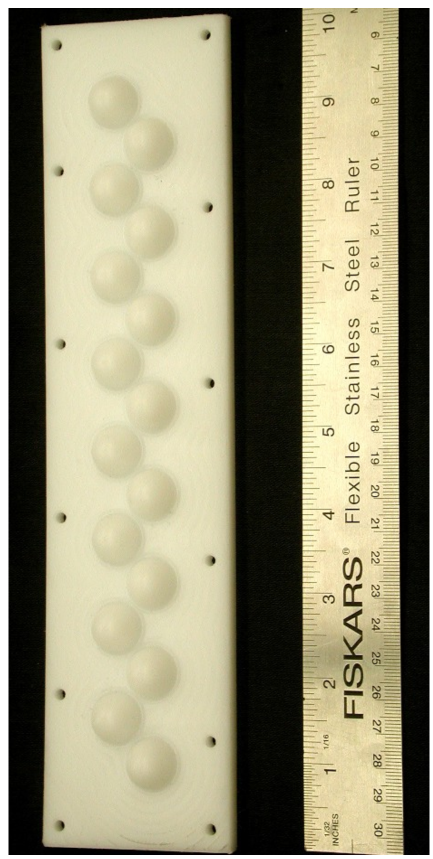

Fig. 1: A mini lens array, consisting of 16 miniature elliptical lenses arranged in a staggered pattern, each with a diameter of 15.24 mm.

III. A Mini-Lens Based System Concept

The new mini-lens configuration is shown in Fig. 2. LO power is introduced from the substrate side of the antenna via

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reflection off a near lossless dichroic plate highpass filter, using a pair of lenses to form a tall, narrow beam at the lens array. Each elliptical lens then focuses the incident ~parallel rays onto the antenna at its focus. This increases the LO power coupled to the dual dipole antenna by more than a factor of 5x. The RF sensitivity is likewise enhanced as the antenna geometry is now optimized for both RF and LO coupling.

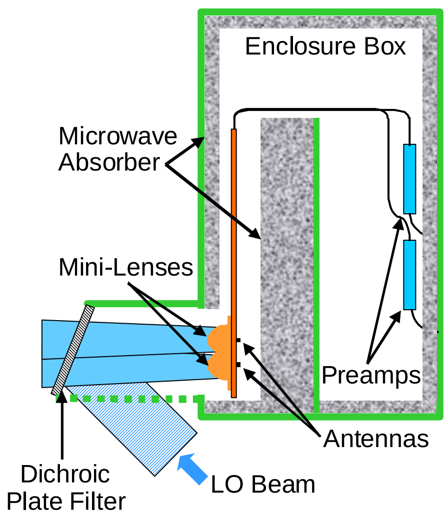

Fig. 2: Top view illustration of the mini-lens concept, with a staggered two column antenna arrangement with front-side LO coupling.

The use of mini-lenses (see Fig. 1) yields significant increases in sensitivity, RF bandwidth, and ECRH shielding. The new mini-lens configuration is shown in Fig. 2. Here, the lens-antenna array is arranged in a staggered two column format producing a tall narrow beam close to the array. LO power is introduced from the substrate side of the antenna via reflection off a near lossless dichroic plate highpass filter, with the elliptical lens refracting the parallel rays to its focus. This increases the LO power coupled to the antenna by more than a factor of 5x. The RF sensitivity is likewise enhanced as the antenna geometry is now optimized for both RF and LO.

An added benefit of the use of mini-lenses is a simplified optics arrangement. While the current TEXTOR ECEI system employs three lenses and a pair of cylindrical mirrors (one E-plane and one H-plane), the mini-lens based system can be as simple as the two lens configuration illustrated in Fig. 3. Axially translating the lenses serves to translate the focal plane of the system within the plasma as well as to vary the focal spot size and plasma coverage. For the configuration shown in Fig. 2, the system has a 15 mm FWHM spot size and a 24 cm vertical coverage (as opposed to the current system with a fixed 12 mm spot size and a vertical coverage of only 17 cm).

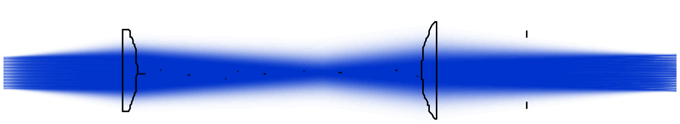

Fig. 3: Gaussian visualization (side view) of a 16 channel mini-lens based ECEI system for TEXTOR, from the array (left) through two lenses (middle) to the image plane in the plasma (right).

A more flexible imaging arrangement is illustrated in Fig. 4, and represents a system configuration to be installed on TEXTOR in September 2008. Adding one more lens adds a vertical zoom capability to the system, allowing the vertical extent and the horizontal position of the ECEI focal plane to be set independently. The two plasma-facing lenses form a zoom lens, and allow the vertical extent of the focal plane to vary from 20 to 30 cm (vertical channel spacings to vary from 13 mm to 19 mm). The next lens provides an independent control of the focal plane position within the plasma. The depth of field of the instrument varies with vertical spot size and frequency, but in all cases exceeds 200 mm. With typical horizontal coverage of ~100 mm, this ensures that all ECEI channels have near optimum focusing. The last lens, placed closest to the mini-lens array, reduces the horizontal extent of the beams to ensure that all imaging signals successfully pass through the relatively narrow vacuum window on TEXTOR.

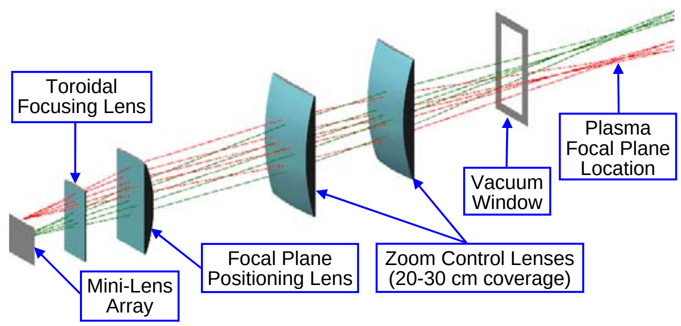

Fig. 4: Gaussian visualization (side view) of a 16 channel mini-lens based ECEI system for TEXTOR, from the array (left) through two lenses (middle) to the image plane in the plasma (right).

IV. ACKNOWLEDGEMENT

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