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ECE measurements via B-X-O mode conversion – a proposal to diagnose the *q* profile in spherical tokamaks

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1. Introduction

The topology of plasma cut-offs and resonances in spherical tokamaks (STs) is quite different from the corresponding topologies in conventional tokamaks and stellarators (see Fig.1). The main reason for this difference is the relatively low magnetic field used for plasma confinement in STs. As a result, the first few harmonics of the electron cyclotron (EC) frequency are usually trapped by cut-offs in the bulk plasma. This situation is quite typical, and makes conventional diagnostics, based on EC plasma emission, difficult in STs with high density plasmas. At the same time, the optical depth of the plasma at EC harmonics is generally very high for electron Bernstein waves (EBWs) in tokamak plasmas [1], but these waves are predominantly electrostatic and can only exist inside the plasma.

There are two mode conversion mechanisms allowing EBWs to transfer their energy to electromagnetic waves, which can propagate from plasma to vacuum. The first way is the Bernstein – extraordinary - ordinary (B-X-O) mode conversion process, originally proposed for plasma heating by J. Preinhaelter and V. Kopecky [2]. Experimentally the O-X-B mode conversion scheme (i.e. the inverse process) has been successfully exploited for plasma heating by Laqua et al [3].

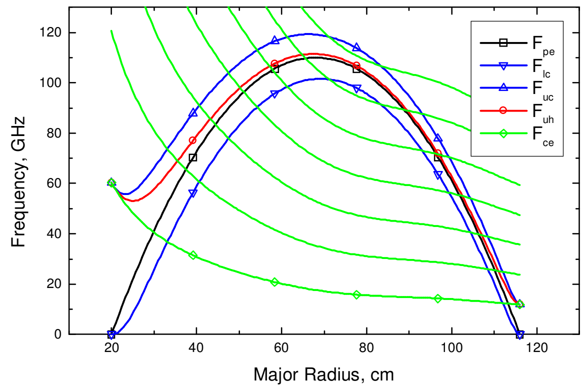

Fig. 1 Topology of characteristic frequencies in MAST

The second way is based on a direct (B-X) tunnelling of the EBWs to extraordinary waves through the evanescent layer between the upper hybrid resonance and the upper cut-off. Obviously, this process can only be effective with a narrow evanescent layer, which requires a steep density gradient at the plasma edge.

These mode conversion schemes make EBWs potentially promising for ST fusion plasma diagnostics. Indeed, because EC harmonics are optically thick for EBWs, each separate resonant surface must emit and absorb power as an absolutely black body. The resonance topology in STs is such that each higher EC harmonic will partially shadow the previous one, if the plasma is observed from the low field side (LFS) (see Fig 1). The resultant EBW radiation as it appears at the upper hybrid resonance layer, where the mode conversion occurs, must show a sawtooth-like spectrum with emissivity gradually rising with frequency. Hence, one can expect the same feature of the electromagnetic emission spectrum in STs if this emission is mainly generated via the EBW conversion scheme. Each step in the emitted spectrum corresponds to the plasma layer where an EC harmonic coincides with the upper hybrid resonance zone in the plasma mid-plane. This gives a local measurement of the relationship between total magnetic field and plasma density. Hence, if the plasma density profile is measured with another diagnostic, one could in principle reconstruct the LFS part of the *q* profile.

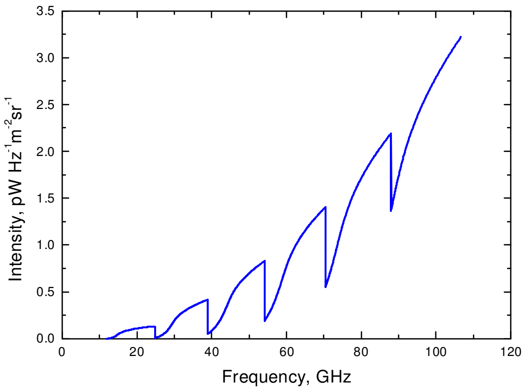

Fig.2 EBWs spectrum estimated for MAST plasma

EBWs can escape through a small angular window determined by the B-X-O mode conversion mechanism. Thus, the ordinary polarised emission of the ST plasma measured at the optimum angle must be mainly determined by the EBW spectrum multiplied by the factor of the B-X-O mode conversion efficiency (see Fig. 2).

2. Experimental system for EBW emission observation

Recently, a new frequency scanning EBW radiometer has been installed on the MAST tokamak [4] for mode conversion studies. It consists of two sweepable heterodyne receivers; the first covers the band of 16-26 GHz and the second one covers 26-40 GHz. A schematic of the heterodyne receiver is shown in Fig. 3. A voltage controlled oscillator (VCO) provides a local oscillator for a second harmonic mixer. The signal input of the mixer is connected via coaxial-to-waveguide transition to the antenna system. The output signal of the mixer, passed through a low noise amplifier and a low pass filter, is split into two parts. One component is input to a linear power detector, which has a dynamic range from –20 dBm to +10 dBm, and the other one comes to a logarithmic power detector, whose dynamic range extends from –70 dBm to 0 dBm. Such a configuration of the heterodyne receiver allows reliable detection of the plasma emission over a wide range of plasma parameters.

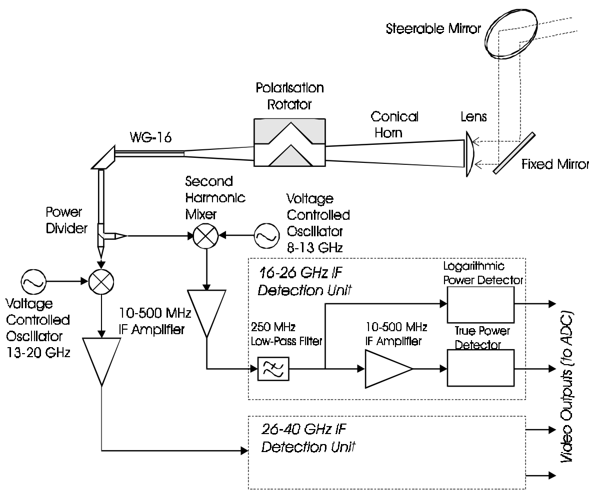

Fig. 3 Schematic diagram of the EBW radiometer on MAST

The antenna system includes a polarisation rotator, conical horn with an input aperture of 100 mm and a periscopic mirror system. This antenna permits us to select a desirable polarisation and a viewing angle in the range of about ±35° in toroidal and poloidal directions. The antenna has been installed on a horizontal port, 20 cm below the midplane of the MAST tokamak.

3. Preliminary results and discussion

For initial experiments the antenna of the EBW radiometer was aligned for X-mode observation with perpendicular viewing to the toroidal magnetic field. The VCOs were controlled with step-wise voltage, which had 16 steps with the duration of each step of 10 μs.

The step voltage generator is synchronised with a CAMAC clock. Such setting of the system defines 32 separate frequency channels in the range of 16-40 GHz. The full frequency scan is completed in 160 μs in parallel for both frequency bands.

Fig. 4 illustrates EBW radiometer signal behaviour during shot #2505. The flat top plasma current of 700 kA and the toroidal magnetic field of 0.57T (R=70 cm) define the value of 13 GHz for the EC frequency at the plasma scrape off layer (SOL) as shown on Fig. 5. This figure is calculated at 140 ms into the discharge, supposing that the density profile measured with Thomson scattering at 100 ms does not change dramatically in the next 50 ms. The second EC harmonic with such plasma parameters appears to be partially open from the low field side (LFS) viewing, while the fundamental EC harmonic is shielded by cut-offs for both modes (see Fig. 5).

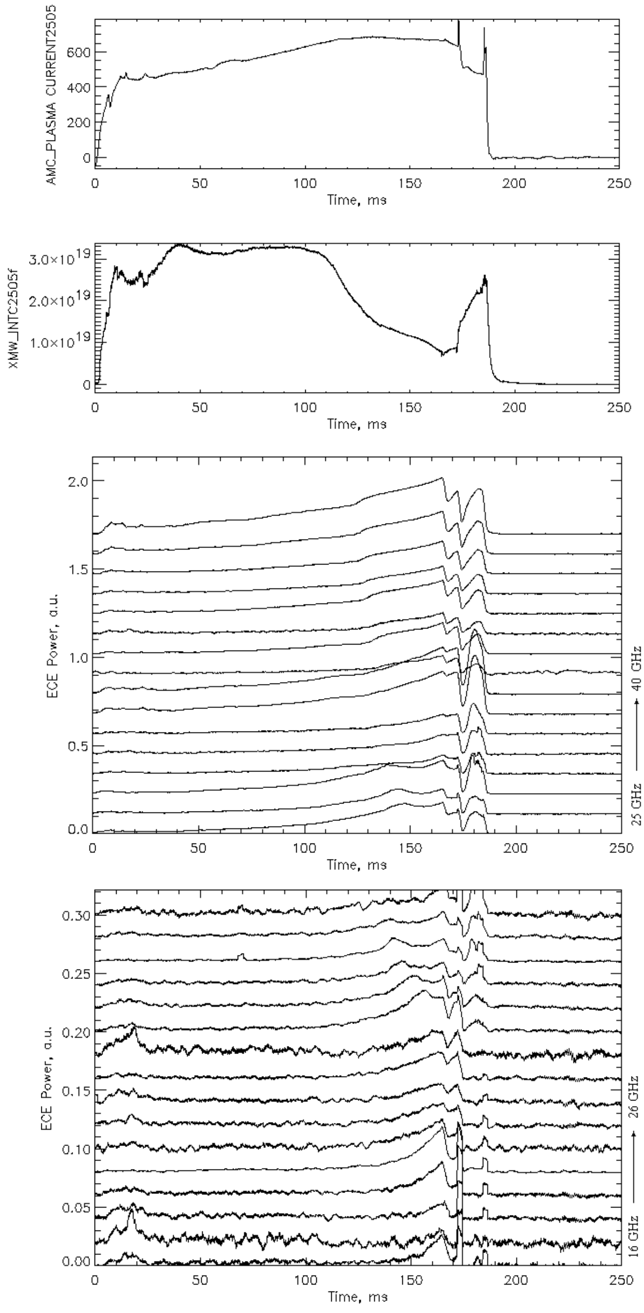

Fig. 4 Plasma current, line integrated plasma density, measured with double pass 2 mm interferometer (m^{-2}) and EBW radiometer signals, logarithmic outputs, shot #2505
lower picture: 16-26 GHz with ~0.6 GHz steps
upper picture: 25-40 GHz with ~1 GHz steps

As a result, one can see gradually rising signals from open parts of the second EC harmonic with one maximum located at 31-32 GHz and another one around 40 GHz. Low frequency channels show some spikes at the beginning and at the end of the shot, remaining quite low during the plasma current flattop. Such behaviour is in good agreement with the plasma resonance topology.

An interesting event appears at 27 GHz starting from 130-140 ms. A clear local maximum in the spectrum appears at that time with further decreasing of the peak frequency down to 23 GHz at 155 ms. No global events were observed in the plasma during this time interval except a plasma density decrease. The existence of this spectral maximum and its dynamic behaviour can be explained by B-X mode conversion at the upper hybrid resonance layer. EBWs come from the fundamental EC resonance layer located in the hot central part of the plasma and the emissivity must be much higher than that for the edge cyclotron emission. It should be noted that Fig. 4 shows logarithmic outputs, i.e. emission intensity changes are quite high during this event.

During the density ramp down the gradient zone in the SOL is moving to lower density. The B-X conversion efficiency is strongly dependent on the density gradient, and with gradient zone displacement to lower densities the optimal frequency for B-X conversion/tunnelling must also move down to lower frequencies as predicted by theory.

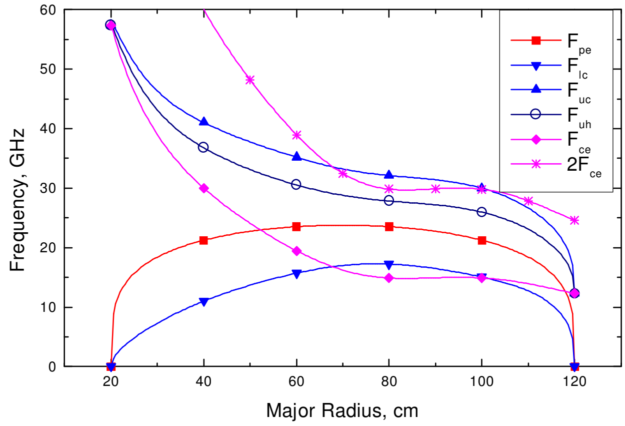

Fig. 6 Topology of characteristic frequencies in MAST, Shot #2505

The spectral width of this maximum is about 3-4 GHz which implies that the density gradient at the conversion layer ($F_{uh} \cong 24$ GHz and $F_{ce} \cong 13$ GHz, hence $n_e \cong 5{\cdot}10^{18}$ m^{-3}) is relatively low. Possibly, because of the existence of low density plasma outside the SOL, B-X mode conversion was not yet observed in MAST with high density plasmas.

4. Conclusion

An EBW radiometer has been installed on MAST. The detailed experimental studies of mode conversion processes via ST plasma emission measurements are at an important stage, not only for EBW diagnostics, but for EBW heating and current drive as well. Initial indications of B-X mode conversion/tunnelling have been observed on MAST.

Observation of power emitted by plasma at different viewing angles is considered as a next step of EBW radiometric measurements on MAST. These experiments will show the applicability of both B-X and B-X-O conversion mechanisms for diagnostic applications and plasma heating in ST plasmas.

Acknowledgments

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