Dispersion Interferometer based on CO_2 - laser

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Dispersion Interferometer (DI) is a specific type of two-color interferometer in which a fundamental laser beam frequency is doubled in a nonlinear crystal. The simplest DI layout includes two frequency doublers. Between doublers the object under study (plasma) is placed (see Fig.1).

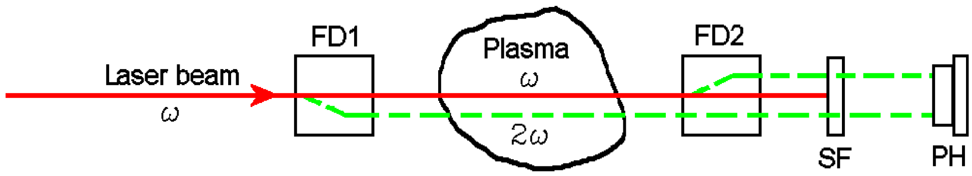

Fig. 1 *Principal scheme of the DI: FD - frequency doubler; SF - selective light filter; PH – photo-detector; solid line - probe radiation; dashed line - second harmonics radiation*

After partial conversion, two harmonics with different frequencies propagate collinearly through the plasma. Then the fundamental ray is doubled again. The resulting interference between second harmonic rays after first and second propagation through the crystal is insensitive to path length but is affected by plasma dispersion. This feature determines the key advantage of DI - low sensitivity to vibrations.

DI based on Nd:YAG laser (λ=1.06 μm) were developed and successfully used for nuclear fusion experiments [1,2,3]. We developed DI based on continues-wave CO_2 - laser source (λ=9.57μm) with double plasma passage for measurements of electron density in the TEXTOR tokamak and the GDT linear machine.

From viewpoint of tokamak plasma, attractive diagnostic advantages of DI based on CO_2 – laser radiation are as follows:

- resolution is high enough for wavelength of fundamental harmonics $\lambda_{FH} \approx 10\mu m$ and second harmonic $\lambda_{SH} \approx 5\mu m$;

- influence of refraction is negligible for conditions of modern fusion experiments;
- low sensitivity to coating and damage of optical components by particle and radiation fluxes from plasma;
- effective frequency doublers with wide spread of synchronism angles are available;
- reliable CO_2 lasers and high-sensitivity IR detectors are commercially available.

Fig.2 shows schematically optical system of DI on TEXTOR. Interferometer does not have any vibration isolation structure and its basic components are installed compactly on the optical table placed on the stable basement outside of plasma device. The exception are the IR entrance window and hollow retroreflector installed inside the vacuum vessel of the device.

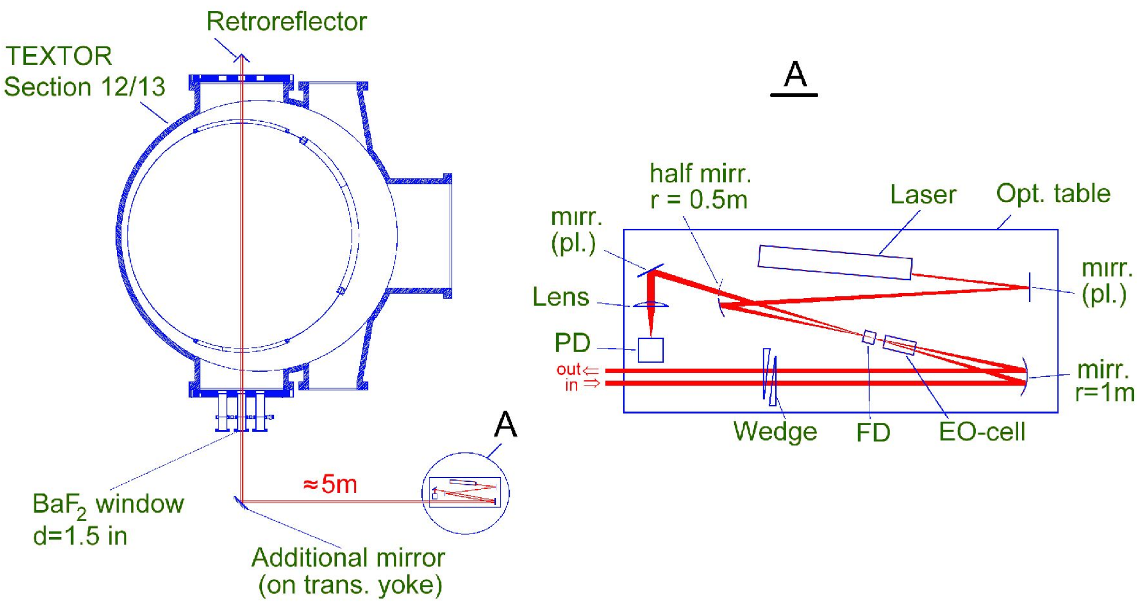

Fig. 2 *Schematic view of DI on TEXTOR: FD - frequency doubler; EO-cell - electro optical cell ; PD – photo-detector.*

Radiation of CO_2 laser is focused by concave half-mirror (radius r=0.5m) into nonlinear crystal $ZnGeP_2$. Fundamental laser beam is converted partially into the second harmonic. Probe beams of fundamental and second harmonics are passed collinearly through electro optical cell, concave mirror (radius r=1m), optical wedge, additional mirror installed on transformer yoke of TEXTOR, infrared window made from BaF_2 and plasma. After reflection from hollow retroreflector probe beams are returned to optical table, passed once again through the optical wedge, electro optical cell, frequency doubler and focused by special lens to IR photo detector combined with selective light filter. Optical wedge is used for calibration.

Electro optical cell is the basic component of special phase detection system, which was developed for DI. It includes also 3 kV 250 kHz modulation unit, analog filters, two – channel 12 bit 32 MHz digitizer and a processor unit. The phase detection system allowed us in principle to measure unrestricted phase shift and to achieve the temporal resolution of few tens of microseconds. The main restriction for phase detection method is: maximal value of derivative of phase with respect to time should be less then $d\varphi/dt \ll \pi \cdot f_{mod}$, where φ is phase shift between interfering waves, f_{mod} = 250 kHz - modulation frequency.

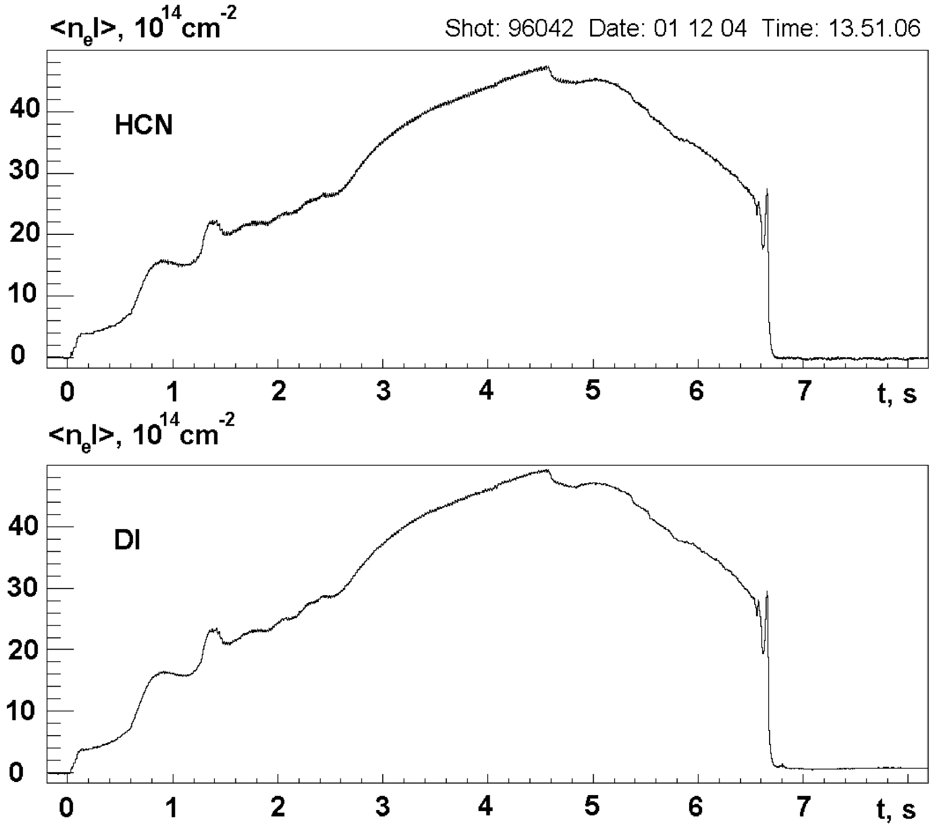

Fig. 3 *Time evolution of electron linear density along the central chord of TEXTOR measured by FIR interferometer – polarimeter based on HCN laser (upper) and DI (lower)*

Experimental data was obtained in a big number of TEXTOR plasma discharges during the experimental campaign in November – December 2004. Fig. 3 shows the time evolution of plasma linear density along the central chord of TEXTOR measured by DI in the shot #96042. Result of measurement by FIR interferometer-polarimeter based on HCN laser [4] along the same chord is shown for comparison. Fig.4 presents the extended part of lower picture on Fig.3. It demonstrates possibility of DI to resolve the sawteeth fluctuations. Based on results of measurement in TEXTOR experiment we can conclude that sensitivity of $\langle n_e l \rangle_{min} = 2 \cdot 10^{13} cm^{-2}$ and temporal resolution of 100μs have been achieved.

Based on experience of development of single-channel DI and measurement in real tokamak experiment one can develop dispersion interferometer with several spatial channels

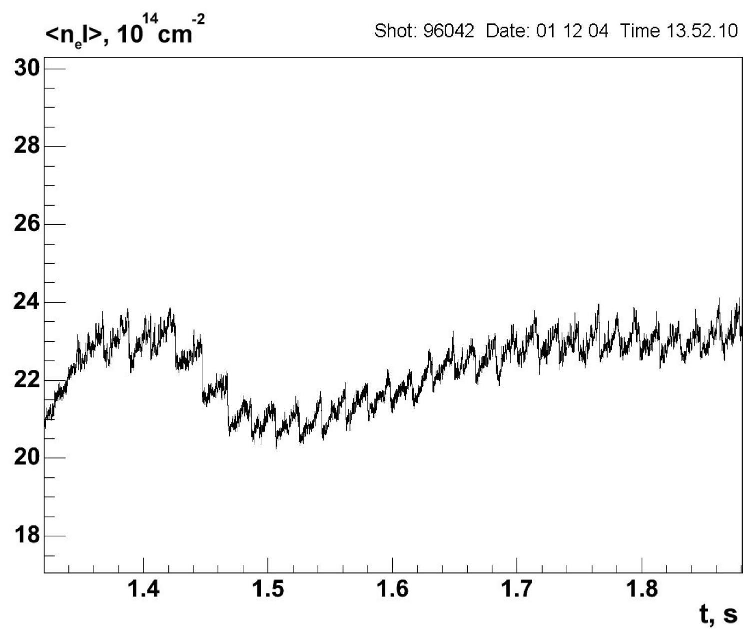

Fig. 4 *Sawteeth fluctuations resolved by DI during TEXTOR experimental shot #96042*

providing both density measurement and a real-time feedback to the system controlling the plasma torus position in a tokamak. The latter feature is critically important for the future burning plasma experiment ITER, where will be no possibility to introduce a frame required for traditional interferometers.

Summarizing materials presented above we can draw conclusions as follows:

- one channel Dispersion Interferometer with double plasma passage was developed and tested in TEXTOR experiment;
- sensitivity of $\langle n_e l \rangle_{min} \approx 2 \cdot 10^{13}$ cm^{-2} and temporal resolution of 100 μs were achieved;
- our experience in development of the one-channel DI and its application in a real experiment can provide a good basis for development of multi-channel interferometer for large devices including ITER in perspective.

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