STATUS OF 30 GHZ HIGH POWER RF PULSE COMPRESSOR FOR CTF3

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Abstract

A 70 ns 30 GHz pulse compressor with resonant delay lines has been built and installed in the CTF3 test area to obtain the high peak power of 150 MW necessary to demonstrate the full performance of the new CLIC accelerating structure. This pulse compressor will be commissioned at high power in 2006. Different methods to provide fast RF phase switching are discussed. The current status of the CTF3 RF pulse compressor commissioning and first results are presented.

INTRODUCTION

The recent progress in the CLIC accelerating structure design makes challenging demands on the 30 GHz RF pulsed power production. Over 150 MW during 70 ns are required to demonstrate the full performance of the new CLIC accelerating structure HDS [1]. To this end, a dedicated beam line, special power generating structure and power transfer line with reduced losses have been designed, installed and commissioned in CTF3 (CLIC Test Facility). In 2006, a maximum 70 MW during 70 ns were delivered to the high gradient test area [2]. This peak power level is twice lower than the new target value. A 70 ns pulse compressor with resonant delay lines [3, 4] has been designed and manufactured in GYCOM [5]. It has been installed in a high gradient test area to provide higher peak power.

CTF3 PULSE COMPRESSOR

The pulse compressor consists of two identical, 9 m long delay lines, made of 50 mm diameter circular waveguides, operating at a low loss H_{01} mode. Each line is equipped with 2 vacuum pumping ports, movable short circuit, waveguide taper and mode converter. The general view of the pulse compressor is shown in Fig. 1. The principle of operating the pulse compressor is similar to the SLED II [3,4]. The round trip RF power losses of 1.8 %, measured at a low power level, are in good agreement with the expected value. The power gain of the pulse compressor as a function of the input pulse length is shown in Fig. 2. The calculation was based on the measured value of the round trip losses for each individual line and the optimised coupling coefficient. As a result 35 MW RF pulsed power during ~ 400 ns will be enough to produce 150 MW, 70 ns RF pulses. However, experimental demonstration of such a power generation capacity is absolutely necessary before the complete integration of the pulse compressor into the CTF3 30 GHz power generation complex. The dedicated tests were done early in 2006. During this test the RF power was limited at 18 MW by the RF breakdown in a WR34 waveguide system, when the pulse length was increasing beyond 300 ns. Facing such a problem, it was decided completely revise the 30 GHz RF waveguide network in CTF3. Finally, a new, square waveguide standard was adopted. This will allow higher vacuum conductance and lower surface electric field. The new waveguide components are in production now [6] and complete replacement of the network is scheduled for the autumn 2006.

Figure 1: The general view of the pulse compressor.

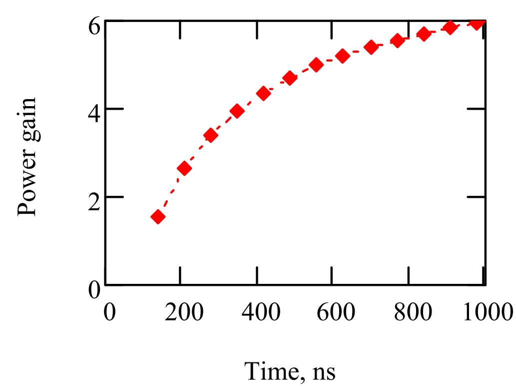

Figure 2: The power gain of the pulse compressor as a function of the input RF pulse length.

To make the pulse compressor system operate efficiently, a fast 180° RF phase flip should be provided. At present it is foreseen to achieve this by switching the CTF3 3 GHz drive beam phase by 18°, which translates into the required 180° at 30 GHz [7]. Dedicated high power tests are planned for 2006. However, this method will remain complicated due to the fact that the speed of the RF phase switching will be limited by the 3 GHz system, in particular by the filling time of the CTF3 accelerating structures. These effects can adversely affect the shape of the compressed pulse reducing the flat top duration, see Fig. 3 for example.

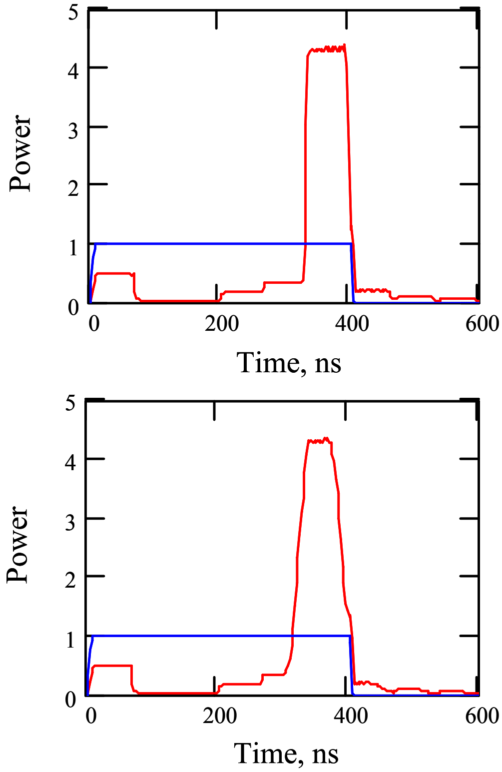

Figure 3: The pulse envelopes reconstructed from the single delay line low power measured spectrum for the two different switching times, 10 ns (up) and 50 ns (down).

A system capable of handling tens of MW at 30 GHz and providing a fast (few ns) electronically controlled RF phase flip would be much easier to operate. High power, high frequency active switches have been proposed and evaluated for more than 10 years, see [8-9] for example. Unfortunately, none of them have yet demonstrated the capability to work at the power levels we are aiming at.

In general, to make RF phase manipulations at constant amplitude, 4-port or 2-port RF circuits can be used. For example, one can think of a standard 3 dB hybrid where 2 ports have short circuits, the positions of which can be electronically controlled. Another approach is to directly control the phase delay (in this case the length) in 2-port devices. In the following we will present a 2-port device as a possible solution for the high power active RF phase switch based on over-moded components developed by GYCOM for CTF3.

ACTIVE RF PHASE SWITCH

The description of the device can be split into two parts: the RF circuit configuration and the method of active control at a high power level. For the second part, we are considering using a solution similar to the one proposed and basically demonstrated in [8], where a short laser pulse of a certain wavelength converts the surface layer of a silicon wafer into the conducting state so that RF power can be efficiently reflected. The detailed description of the underlying process is discussed elsewhere [8, 10]. For the RF circuit, we suggest the use of an over-moded 90° mitre bend. Three such devices were installed and successfully operated at high power in the CTF3 transfer line. In this device, the mode mixing technique is used [5].

The principle of operation of the active RF phase switch is illustrated in Fig. 4. The thin silicon wafer is attached to the copper mirror providing good thermal contact. The incident RF power goes through the wafer, resulting in a certain RF phase advance due to reflection at the backplane of the wafer. At the required moment, a short laser pulse (few nanoseconds) irradiates the semiconductor surface and converts it into the conducting state, such that RF power is reflected at the wafer's front plane, resulting in a fast 180° RF phase flip. After about one microsecond the surface of the silicon wafer will restore the initial state and the device will be ready for the next pulse.

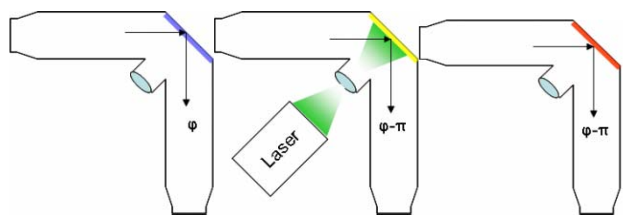

Figure 4: The three stages of operation of the high power optically controlled active RF phase switch.

Compared to other proposed schemes, this scheme provides certain advantages: due to the large surface area, the surface electric field strength will be significantly reduced; this allows for high power capability. The absence of field at the periphery of the mirror makes it easy to install and leaves enough space to introduce the laser beam and vacuum pump feed-throughs. The direct thermal contact of the wafer to the copper mirror will reduce the overall heating of the silicon wafer during operation.

Detailed theoretical and numerical analysis of the device operation confirmed the validity of the proposed approach [11]. The initial tests at a low RF power level showed that the switching of the silicon surface state, when irradiated by the laser beam can be done within a few ns. The test set-up layout and the tests results are shown in Fig. 5.

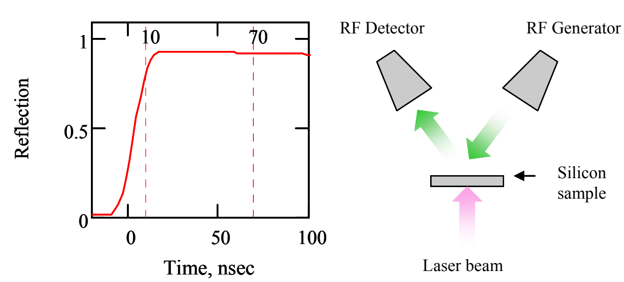

Figure 5: Amplitudes of the reflected power from the silicon wafer before and after the laser pulse.

To minimize losses in the passive state of the switch and hence to reduce the thermal heating of the silicon wafer, we need to have a very pure semiconductor material such that the intrinsic carrier density is very small. In the active state, when the plasma layer is excited, the carrier density should be large enough for the semiconductor to act as a good conductor and thus minimize the losses. We have simulated with HFSS and ANSYS the average temperature of the silicon wafer for a 100 Hz repetition rate and direct water cooling of the copper mirror. For our frequency, a loss tangent of 10^{-3} of the high-resistivity silicon was taken [8]. Assuming 20 °C cooling water, the maximum average temperature of the silicon wafer should be 45 °C. The RF losses in the silicon are very sensitive to its temperature. One way to reduce them is to use special doping. In [12] it was shown that the use of gold as doping agent can reduce the loss tangent of the high-resistivity silicon down to few 10^{-5} at 30 GHz. This, together with direct cooling of the copper mirror will completely solve the problem of silicon wafer heating.

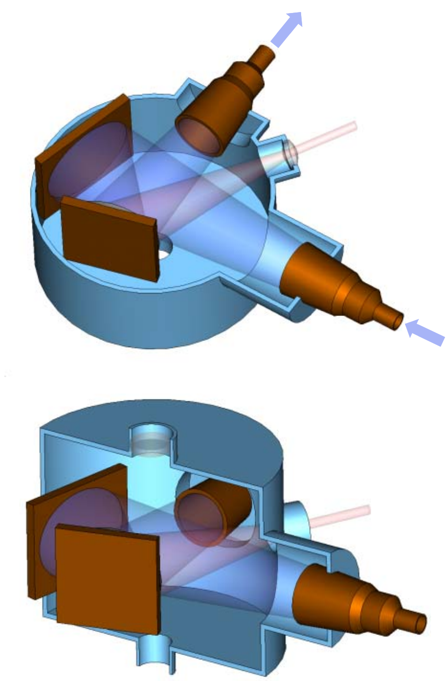

Figure 6: The artistic view of the 30 GHz high power active RF phase switch. Courtesy of GYCOM.

The technical realization of the high power active RF phase switch required some development to provide all features. The two-mirror solution was adopted finally as the most effective, see Fig. 6. Here focusing mirror is placed prior to the flat mirror. The flat mirror is equipped with a silicon wafer of the specified thickness. This configuration allows increased space (volume) for the laser feed through installation. The vacuum pumping ports and water cooling channels are also integrated into the system. The full prototype of the switch is now under construction in GYCOM. The first high power tests in CTF3 are planned for the late 2006 to verify the high power capability of the silicon. If successful, the laser installation and first full scale operation will start in 2007.

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